BOOKS FOR MILLIONS

# SCIENCE SNIPPETS

*Books for Millions*

# SCIENCE SNIPPETS

## (A SCIENCE WRITER'S MISCELLANY)

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# Preface

A few months ago, Dr. S. S. Shashi, Director, Publications Division of the Ministry of Information and Broadcasting, invited me to write a short popular science book in a new series. He planned to publish in order to promote wide diffusion of what Nehru called 'the temper of science' among our people. The present book has been written in response to his invitation.

In writing it I had two options. One was to write an intelligible/jargon-free exegesis of some of the major concepts of a single scientific discipline such as astrophysics, biochemistry, genetics, electronics, quantum mechanics, mathematics or what have you. The other was to compile a miscellany of science snippets culled from a wide diversity of disciplines. In writing this book I have opted for the second alternative to extend its appeal to a wider range of readers.

I hope the book will provide the reader a bird's eye view of some aspects of the progress of science at its frontiers in a number of disciplines like seismology, astronomy, biology, automation, medicine, computers, *et al*

**JAGJIT SINGH**

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# Nuclear Winter

Nuclear winter is the name given to the combination of conditions likely to arise in the wake of a nuclear war. Recent studies of the climatic effects of nuclear war by several groups of scientists in U.S.A., Europe and USSR suggest one consensus conclusion. It is this. In the aftermath of such a war vast areas of the earth would be subjected to prolonged darkness, abnormally low temperatures, violent wind storms, toxic smog and persistent radioactive fallout. After a brief period of nuclear fireworks and fireballs there would ensue a long deep freeze of the continents.

We know, of course, that a major nuclear war between the superpowers would result in instant mega-deaths in the principal target zones of the northern hemisphere compounded by widespread breakdown of transportation systems, power grids, agricultural production, food processing, medical care, sanitation, civil services and civil government. But these instantaneous consequences of the war are nothing compared to its long term after-effects. It is feared that the fine dust raised in high yield nuclear surface bursts and smoke from city and forest fires ignited by outbursts of all yields would cause irreversible changes in global climate leading to the extinction of many species of organisms including the human species.

It is now generally believed that the some of the mass extinctions of species—like that of the dinasours 70 million years ago—were caused by immense clouds of dust raised by the impact of an asteroid or a comet. The dust clouds raised by a nuclear exchange by superpowers would be even more lethal. It has been estimated by Richard P. Turco, Owen B. Toon, Carl Sagan and others that a nuclear war involving less than 40 per cent of the strategic arsenals of the two superpowers could easily raise 100 m to 300 m tonnes of dust and smoke into the atmosphere. Even 100 m tonnes of smoke uniformly distributed over the entire globe could reduce the intensity of sunlight reaching the ground by 95 per cent. Since the initial clouds would not cover the entire globe, large areas of the northern hemisphere, particularly in the target zones, would be even darker. So dark, indeed, that noon brightness would be lower than that of a moonlit night. Daytime darkness in this range, if it persisted for weeks or months, as it might, would trigger a climatic catastrophe.

It would lead to a dramatic drop of around 46°C in continental temperatures for a prolonged period. When we recall that a decrease in average temperature of only a few degrees Celsius in spring or summer could destroy crops through north temperate zone, the consequences of such a steep drop as 46°C in continental temperatures can readily be imagined. One such consequence is the sudden transformation of the atmosphere from a window for sunlight into a blanket of heat thereby greatly attenuating its capacity to raise the average ground level temperature well above freezing and providing a favourable environment for forms of life, like ours, that are based on liquid water. Such a transformation is certain to lead to the extinction of the survivors, if any, of the nuclear haulocast. This is why the long-term destruction of the environment and the disruption of the global ecosystem would in the end prove even more awesome for mankind than the short-term devastation of nuclear explosions and their radioactive fallout.

Similar poisoning of our earth's ecosystem would result even if only one side mounted a pre-emptive strike massive enough to disable the enemy from retaliating with a single bomb or missile of his own. The victor's strike would boomerange because after a month or even less the black blanket raised by his explosions in the enemy zone would irrevocably circle the earth and smother the victor as well as neutrals of the southern hemisphere assuming that that portion of the world escaped the missiles themselves. Victor, vanquished and neutral would thus go the same way of all flesh in a matter of a few weeks. The time has therefore come when the people of the World combined to call a halt to the superpower nuclear arms race as well as to demand dismantlement of the rockets and missiles aimed at each other. Their complete dismantlement is our only escape from the Damocle's sword of mutually assured destruction (MAD) hanging over our necks.

## Star Wars

In a famous 'strategic Defence Initiative (SDI)' commonly known as 'star wars' speech delivered in March 1983 by President Reagan of USA, spelt his vision of a futuristic shield against nuclear attack. He hoped that his military researchers would be able to develop a high energy laser that could foil a nuclear missile attack, blind spy satellites and destroy battlefield targets.

The lure of laser weapons is that they would send destruction of its way at the speed of light – nearly a million time faster than sound. Accordingly a laser beam chasing a supersonic ballistic missile would overtake it almost at launch even if it wer travelling at twice the speed of sound. Interception, during the boost phase, before the attacking missile can deploy multiple warheads, would therefore be the heart of the new weapon system.

Military researchers have identified a range of technologies to accomplish such a task. They include different types of lasers such as X-rays lasers, so-called excimer lasers emitting in the ultraviolet and fee-electron lasers which promise efficient operation over a wide range of wavelengths. But all of them are still in a very early stage of development. They require several years of further research to turn them into practical weapons.

Although many of the proposed technologies for turning laser in a weapon are highly speculative, the United States and the Soviet Union are already spending billions of dollars on what may aptly be called 'star wars' weapon research. It is a technological extravaganza that is likely to dangerously destablise the balance of power, not to speak of further diversion of huge resources to even more wholly infructuous purposes than is the case at present.

## Language and Noam Chomsky

The chief merit of Chomsky's linguistic studies in the 1950s is the rehabilitation of natural language as a medium of human discourse. In the preceding decades natural language was attacked on two counts. First, the logical positivists, influenced by the mathematical logic developed by Gotleb Frege and Bertrand Russell, concluded that natural language was something primitive, vague, inaccurate and confusing. This conclusion in turn gave rise to the claim that the symbolism of modern logic devised by Frege, Russell and others represented the grammar or syntax of an "ideal" (synthetic) language. It was this "ideal" language of their invention which was to take the place of imprecise natural language to embody scientific thought. But as a large part of ordinary and philosophical discourse, particularly metaphysical and moral issues, could not be captured by their "ideal" synthetic language, they branded all such talk as nonsensical or, at least, "cognitively" meaningless. The upshot was the logical positivists prolonged, but largely unsuccessful, endeavour to formulate a criterion of meaningfulness in terms of empirical verifiability with respect to sentences formed in natural language.

The positivist critique of natural language was given a new twist just before the outbreak of World War II by the linguistic anthropologist B.F. Whorf. His famous thesis of linguistic relativity implied that the particular language a person learns and uses determines the framework of his perceptions and thought. If that language is vague and imprecise as the positivists claimed or is brudened with the prejudices and supersititions of an ignorant past, as some cultural anthropologists averred, then it is bound to render the user's thinking and his mental life itself – confused, prejudiced and superstitious.

Natural language was rescued from the combined onslaught of both the logical positivists and Whorfian anthropologists by Noam Chomsky's development of transformational or generative grammar. The starting point of his grammatical studies of language was the fact that every user of a natural language can construct and understand sentences that neither he nor anyone else has come across before. He laid bare the rules of the generative grammar that underlie its *creative* power, which practically all human beings manifest very early in life. Instead of merely providing a structural description (parsing) of sentences he demonstrated how sentences are built step by step, from some basic ingredients. He thus showed that although all natural languages have the same deep structure, their surface structures are bewilderingly diverse. This fact was the warrant for his conclusion that the human mind has elaborate innate language learning per-dispositions which are common to the whole species.

The powerful new view of grammar that Chomsky expounded has helped the philosopher not merely to counter the positivistic charge of imprecision laid against natural languages but also to aid him in his own work of conceptual classification. Moreover, Chomsky's generative approach has now paved the way for the development of a generative semantics for natural language as a supplement to generative syntax.

## Sociobiology

According to its founding father, the entomologist Edward O. Wilson, sociobiology is a new discipline that seeks to "develop general laws of the evolution and biology of social behaviour" and to extend such laws to the study of human beings. It is a great merit of Wilson's earlier entomological research to show how the pattern of social behaviour of ants and bees is rigidly programmed by heredity independent of environment. Carried away by the purely genetical determination of social behaviour of ants and bees, Wilson proceeded to inflate entomology into sociobiology the new grand science of the future, and the great rendezvous of not merely of sociology, economics and politics but also of diverse life sciences like evolutions, genetics, neurophysiology and psychology. The takeover of all these disciplines by sociobiology was intended to "dig deep in our biological histories to understand and quantify human nature" in order to make it as "predictable" as the behaviour of inanimate matter by physics and chemistry. But in actual practice, the claim that it provides an explanatory basis for predicting the behaviour of humans, individually or in groups, is scientifically spurious. The reason is that the whole sociobiological approach is riddled with four fundamental fallacies.

First is the fallacy of reification. That is, sociobiologist take a process with a dynamic and a history of its own involving individuals and their relations we call social interaction. They then isolate an abstract underlying fixed thing, or "quality". Such, for instance, is the case with an individual's logical and numerical skills, his reading ability, his capacity to recognise geometrical patterns or, divine riddles and the like. All these diverse skills are lumped together to measure an underlying unitary faculty called "intelligence". An inevitable consequence of this bulldozing procedure is that the fixed and reified property becomes attached to an individual rather than emerging from a situation in which he is involved. It is individuals who then become intelligent, aggressive, altruistic, selfish or what have you, and the same property becomes manifest in different circumstances.

The second fallacy is the unwarranted quantification of the reified "quality" like intelligence. A classic instance of such spurious numerology is the infamous IQ that has been used as a political tool to downgrade a particular class or race of people.

The third fallacy is the appeal to "biological" evidence from the study of insects and non-human animals in order to apply it to human beings. But the evidence gathered is manipulated to show that such disagreeable tendencies of human behaviour as selfishness, spite, antisocial, violence etc. are virtually "instincts" inalterably fixed by our evolutionary past, that is, the genes that have promoted our survival.

The fourth fallacy is that most of its propositions are either vacuous tautologies or self-fulfilling prophecies incapable of experimental refutation.

Because of this four-fold set of fallacies embedded within it, sociobiology has become an apologetics of rightist ideologies that deny outright the possibility of human nature and social behaviour to transform itself with changing historic conditions. Their main message is that human nature being "genetically determined" does *not* change despite all changes of society from palaeolithic to neolithic, to preindustrial feudal to carboniferous capitalism of the industrial revolution and to the advanced one of today.

## Science and Religion

Broadly speaking there are only two world pictures which man may form of the universe around him. First, there is the scientific world view which considers the universe as potentially explicable by rational enquiry based on ordinary observation. Second, there is the religious mystical-cum-mythical picture of the world ruled by an Almighty God who may or may not be assisted by an hierarchy of subordinate angels or gods. The conflict between these two antipodal views is nothing new. It existed in an acute form in antiquity almost since the scientific world view sloughed off the religious myths of ancient civilizations. I will not take time to dwell on this sloughing off process that led to the emergence of the scientific world view. I will instead confine myself to the history of their conflict that began with the advent of the Copernican Revolution.

At first in a timid faltering spirit Copernicus suggested his new heliocentric theory of planetary motions as a convenient "mathematical fiction" while still acknowledging the "truth" of the stationary earth biblical theory. Kepler, who discovered the three laws of planetary motions that bear his name after a prolonged empirical study of planetary positions, found in them primarily an expression of the beauty and harmony of divine creation. Even Newton, whose celestial mechanics was to provide the basis for the subsequent development of the belligerent anti-religious philosophy of the mechanical materialists, was himself a fervent theist believing in Revelation and Apocalypse. Although in his scientific work he adopted on the whole the method of rational enquiry, it seems that he did entertain the suspicion that God, the creator of the world, must intervene from time to time to prevent the planets from colliding with one another or falling into the sun under the action of their mutual perturbations. When, therefore, Lagrange and Laplace, later showed by clever mathematical proofs that the planetary system possesses "stability" of itself on the basis of Newton's laws, the classic boast of Laplace to Napoleon that "we have no need of the hypothesis of God" was fully justified. From this moment onward science began to wage an all-out war against religious beliefs and superstitions both popular and organised with increasing success. James Hilton's geological history of the earth, for instance, undermined the naive religious beliefs about our earth's creation exactly as Darwin's theory of biological evolution demolished the biblical myth of man's emergence on earth by a fiat of God. This scientific movement demolishing religious myths and beliefs reached its apogee around the turn of the century when the publication of Haeckel's widely read masterpiece, 'The Riddle of the Universe', carried the message of science to the layman. It was simply a demonstration that the findings of science were in total discord with religious beliefs from which there could be no escape except by abandoning the teachings of religion.

But this victory of science over religion proved pyrrhic after all. For during the first three decades of the 20th century the classical scientific method hitherto followed in physical science suffered a serious breakdown. The Newtonian mechanics so successful in explaining the motions of macro bodies like planets in the sky and projectiles on earth failed to account for the motion of newly discovered micro entities like sub-atomic particles and photons of light. To explain them, scientists had to resort to new esoteric notions like wavicles, a portmanteau word coined by packing together waves and particles, – a strange incomprehensible amalgam of both. Such apparently paradoxical concepts as wavicales were accepted because they seemed to "work" after a fashion.

The 'wavicale' crisis in physics made science more and more self-aware of its own limitations rather than its power. This shift in scientific attitude is clearly visible in the emergence of what Sir Arthur Eddington called principles of impotence. In sharp contrast to the principles of power like that of Laplace's cosmic calculator, who could predict the entire past and future history of the cosmos given its initial status at any single instant of time and the laws of nature at work, scientists now showed that they could not even "in principle" do certain things hitherto deemed all but within their grasp. The *coup de grace* was delivered in the 1930s when the celebrated logician Kurt Godel showed that there are *true* propositions that cannot be proved within any possible set of self-consistent axioms. For no worthwhile axiomatic system could be both consistent and complete!

The increasing awareness of the limitations of science has led many scientists to suggest that the relation of the natural sciences to religion should be re-checked to determine whether the belligerently anti-religious stance of the natural sciences culminating in Hacckel's time is still valid today. Many of them like John Eccles, Karl Jaspers, Paul Tillich, have argued quite plausibly that there is a mythological dimension in all sciences now. They claim that science has to accommodate mythology because some problems are all but insoluble otherwise. Such is the case when we attempt to solve the super problems of origins whether of life, mind, consciousness or the universe. Some of them like the origin of life are only partially soluble leaving room for chance and contingency to have ample play. Others like the origin of the universe may well be insoluble in the way squaring a circle is, still others may be insoluble because they are of the same class as that of the Cretan Epimanides who said "All Cretans are liars" and then acquired mischievously whether he was lying or speaking the truth. Whatever way his question is answered there is a paradox or problem. It is quite likely that the mind/body problem is one of this kind. For mind is both the subject of investigation and the means by which it is pursued. As P.W. Medawar has suggested this form of insolubility may be described as "incompletability" just as the portrait of a studio which includes the painter himself sitting at his easel with canvas in front of him is essentially incompletable. In such problems of self-reference where thoughts and concepts appear to loop back on themselves like the nested flashbacks or plays within plays, the solution escapes through linguistic crevices like water in a sieve.

These three kinds of problems, the partially soluble, the wholly insoluble and the incompletable ones because of self-reference wil give rise to new myths. They may be more refined than these of the primitive man. But they are essentially alike in that they provided explanations that cannot be questioned.

Because of the newly discovered quasi-mythical dimension of science I have just mentioned, the debate between science and religion is curiously muted today. When it forces itself on the reluctant mind, scientists face it in a variety of ways. Some dismiss it as a game not worth playing and relapse into a sort of doublethink, though not without a prick of conscience, which they try to soothe by rendering unto the Ceaser of science the things which are Ceaser's and unto the God of religion the things that are God's. Others seek some subterfuge, equivocation, or *double entendre* like the Nobel Laureate, Sir. W.H. Bragg, did when he proclaimed that science is opposed to religion in the sense that the thumb and fingers of hand are opposed to one another. He asserted, perhaps tongue in check, that it is an opposition by means of which anything can be grasped, confusing thereby the grasp of reality by the human mind with the grasp of an object by the human hand. Still others believe that the advent of new ways of exploring micro phenomena like particle physics or solving super problems or origins does not alter the fundamental premises of scientific approach. The more science changes in its outward appearance to deal with new problems, the more it stays the same at its basic corelogical theory verified by contrived experiment and empirical observation. It therefore concedes no more living space to religion that its older variant did. According to them religions, at best are sterile but genuine flowers on the tree of human culture. At worst, they are the opium of the masses especially if people appear to lack the temper of science as is the case in developing countries like ours. It is the last mentioned Marxist-Leninist view of the relation between science and religion that seems to me the most credible.

## Eugenics

*Eugenics* is the application of knowledge of heredity to the improvement of the human race. The idea is nothing new. It is as old as Plato who eulogized in his *Republic* a society where there is constant selection for the improvement of the stock. But the term is a recent innovation. It was coined by Francis Galton who first suggested that Darwin's theory of evolution implied that we could direct our own evolution. But as the mechanism of heredity underlying evolution was not then known, the means devised did not match the goal. As a result, the enugenic movement he founded degenerated into merely countering the supposed threat to civilization by the "lower" races outbreeding the "higher" ones. Most eugenists of the time and the first four decades of the 20th century believed the Hitlarite herrenvolk myth that the white race was superior to other races, and the "Nordic" white to other whites.

Recent advances in genetics and molecular biology have discredited the racist beliefs of Galton and his followers like Karl Pearson. But the work done at the Galton Laboratory in London he founded paved the way to all modern research on the subject: research which was eventually to give rise to a new branch of medicine. It began with geneti counselling, followed by programmes of geneti screening—for hereditary diseases like sickle cell i blacks and Taysachs in the Jewish population. The came aminocentesis, and latterly, chorionic biops making it increasingly possible to detect geneti abnormalities in the womb and selectively to abor them.

The rapid progress with which human genes are now being allocated to identified regions of individual chromosomes bids fair to bring under control a majority of hereditary disorders. The number of genes already allocated or mapped has increased from a few to over 900 in the past decade. Of these about 250 have been cloned, that is, vegetatively reproduced like cuttings from plants. In addition, the number of regionally located genetic (or DNA) segments in chromosomes that are *not* genes is over 800. Such segments or bits of DNA are called 'probes' because they help locate the genes in the chromosome.

The mapping of genes in the chromosomes in which they occur has clarified the molecular basis and pethogenesis of many hereditary disorders due to single gene. Consider, for instance, the inherited disease of unknown aeteology and pathogenesis called PKID, short for polycystic kidney disease. Recent research has shown a close linkage between

PKID and the — globin gene located on the short arm of chromosome number* 16. The finding means that genetic counselling in affected families should soon be possible when ‘probes’ bridging PKID are identified. Since many of the genes already mapped are related to human disorders, diagnostic procedures can be rapidly developed as, for example, in case of Von Willenbrand’s syndrome whose sponsoring gene is on chromosome 14, and Wilson’s disease whose guilty gene is mapped to chromosome 13.

We are now a little closer to Galton’s goal of directing our own evolution though we have still a very long way to go. We are merely discovering some of our defective genes in order to get rid of them. We have as yet no clue to genes or, constellation of genes, sponsoring talent, genius, or character. But, I fear, we will not know what to do with them when we find them. Genetic engineering of ‘genius’ genes is not so simple as getting rid of a defective one.

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* Twenty three chromosomes in the human gerome are serially numbered 1, 2, 3.........22. The twenty third chromosome is labelled X (female) or Y (male).

# A New Approach to Evolution

A variant of the anthropomorphic approach t biological evolution adopted by Richard Dawkins i his famous book, *The Selfish Gene* is the accountan approach of "optimality theory". Optimization is familiar tool of accountants who try to compare th costs of diverse alternatives available with th benefits accruing from their adoption. It is bein routinely applied by operation researchers, desig engineers, system analysts, physcists and others to a range of problems from ballistics to distribution o wagons for optimal transport of materials.

Its application to evolutionary biology, however, is a recent innovation. It stems from the tacit assumption that 'natural selection', the guide that pilots biological evolution, is a natural optimising agent not unlike Dawkins' "selfish" genes that make us carry grist to the genetic mill.

The argument given in favour of optimality theory of evolution is this. Genetic variation within populations means that some individuals survive by better adaptation to environment than others that don't. Natural selection leads to a gradual domination of the former sort and extinction of the latter. It is, therefore, an agent that brings about an increasingly closer "fit" between organism and environment. It is at this stage that optimality theory intervenes to supposedly enable us to predict the sort of adaptation that will evolve. Its exponents claim that like any design problem, all adaptations have "costs" and "benefits": "benefits" in terms of providing a solution to some problem of survival such as finding food, and "costs" in terms of compromising survival prospects in other ways like increasing vulnerability to predators. Natural selection is nature's optimizer which hits on the adaptations that maximises the benefit-to-cost ratio.

But natural selection does *not* operate in this way, the way a human designer evolves optimal design features, For optimization means balancing costs and benefits. Obviously natural selection cannot ascertain the likely costs and benefits of various alternatives possible. All it can do and actually does is to float them all on the sea of environment and let them sink or swim. It does so by spewing alternatives, not by recourse to an optimal theory, but by random processes like continual gene shufflings by sexual reproduction and altering old ones by equally random mutations. In all such random mutations and juggling of genes, it has as little use for optimality theory as a design engineer who stumbles to his design by random shufflings of design parameters. It, therefore, seems to me that optimality theory is not likely to illumine the course of biological evolution any more than the "selfish gene" theory of Richard Dawkins and his school.

# Biology in Space

Life on earth exists in an environment of constant gravity. Aquatic animals living in water remain in a state of weightlessness or zero gravity because the buoyancy of water neutralises earth's gravity. Land animals, on the other hand, live under the constant stress of earth's gravity, usually called one-g condition. Both types have accommodated themselves to the constant gravity either zero or one of their respective habitats. The situation for land animals like man and his pets, however, has now changed dramatically with the advent of space age. Gravitation, hitherto a constant parameter during the aeons of their evolution on earth, has now begun to vary in the range between one-g (earth condition) when on land and zero-g (weightlessness) when on board a spaceship.

The experience gained during prolonged flights in space shuttles has shown that this shift from one-g to zero-g, or a state of weightlessness lowers the human body's immunity to disease. It seems that human white blood cells or lymphoytes, the main guardians of the human body against foreign disease carrying pathogens like viruses and bacteria, do not like the change to a state of weightlessness. It dampens their alertness to challenge the invading pathogens. It is, no doubt, not yet possible to observe their behaviour *in vivo*. But experiments in space have been performed to determine their activity when "Challenged" *in vitro* by appropriate chemicals such as cincanavolin that stimulate cell division. Such experiments show that lymphocytes in a test tube are far less active in the "weightless' environment of a space shuttle than on earth.

Although such *in vitro* results are no indication of lymphocytes behaviour *in vivo*, there is apparently a connection of sorts between their activity and the weightlessness or 'gravity' of the environment, wherein they are nurtured. When they are nurtured in centrifuges on each simulating an environment of 10-g, tenfold weightier than on earth, they are far more active. *Prima facie* the "weight" or "gravity" of the environment plays a significant role in stimulating or retarding their activity. The aforementioned *in vitro* results may therefore well be a partial explanation of the observed fall in the immunity of astronauts on their return from space.

## Plant Breeding

*Plant Breeding* is an ancient activity that is now on the threshold of new breakthroughs. The emergence of modern compedium of techniques collectively called "genetic engineering", a number of possible improvement now in the offing are increased yield, better quality, higher resistance to disease and/or of frost, dispensing with fertilizers by "fixing" nitrogen directly from the air, and the like.

Consider, to begin with, yield of plants, a modern cereal, fruit, or vegetable may outyield its wild ancestors 10, 20 or even 100-fold. But these increases, enormous as they are, have occurred despite the persistence of inefficiencies of the natural processes of growth. They could be increased more if we could, for instance, speed up the slow uptake of nutrients from the soil and/or tardy capture of carbon from air by photosynthesis. New ways of accelerating such growth processes of nature now being devised bid fair to give rise to truly spectacular yields.

Take next the question of improving the "quality" of plants. One way of doing so is to combine the qualities of existing crops that are by nature incapable of sexual fusion like imbueing the potato, for example, with some of the qualities of disease resistance found in some varieties of tomatoes. Another is to superimpose on to cereals the capacity possessed by beans, to "fix" gaseous nitrogen directly from the air and thus make their own fertilizer. This may well prove to be the next big leap after the domestication of wild cereals with which agriculture began.

For such a fusion feat can only be accomplished by crossing the sexual barriers that inhibit the production of new varieties by spectacular marriages of unrelated plants like wheat and beans.

If we can devise techniques to overcome these sexual barriers, they may conceivably even enable us to combine the genomes of plants and bacteria, or of plants and animals leading to a faster production of new and better varieties.

If and when these techniques of fusing the genes of plants with those of bacteria and animals are devised, we may well dream of cereals that can thrive in sea water, of potatoes and grains in brackish water, of tomatoes that defy frost, and of other wonders we can't even imagine now.

## The Biosphere

The earth is the only planet in our solar system that has a biosphere. Other planets and satellites have, like the earth, a core, a mantle and even a crust and atmosphere. But they all lack the biosphere, the most distinctive and interative component of our earth. Only here are the structures that can replicate themselves thereafter evolve into different forms by mutation and genetic recombination and transmit such changes to their progeny.

Structures that can do such things are said to be living, and it is their integration everywhere on and near the earth's surface with its outer crust, oceans and atmosphere that constitutes the biosphere. The most remarkable event in our earth's history is the origin and early diversification of life which gave rise to the biosphere itself. The diversity and interactiveness of the biosphere are too rich to be comprehensible and the potential variety within its collective gene pool too staggering to be imagined. We have so far catalogued some 1.5 m species of animals and .5 m species of plants. But the count is far from complete. It is growing at the rate of some 10,000 new species per annum. We still do not fully understand the far reachig ways in which the evolution of these mysiad species has modified the history and the surface features of our world and has in turn been modified, over the four billion years since the earth's surface became habitable. But we do know a few broad facts of our biosphere's history.

First, the biosphere was not always like what it is now. Today, few places on the earth's surface, or below it for some tens of metres, or above it to a height of nearly 10 kilometres, are now so hot or cold or dry or polluted or exposed to lethal ionizing radiation that they are truly devoid of life. It was not so in the beginning. It took a long time for earth to produce niches hospitable to life. Nor did these primeval precursors of life on earth survive the emergence of new forms of life to which they gave rise. This is why the major work on the biosphere was then done very differently from the way it is being done now by its currently most conspicuous constituents, the familiar multicellular plants and animals of the field, stream and sea.

In the course of the biospheres' known history its geochemically most influential members have always been those of the microbial realm. They are the humble microbes which are morphologically simple but biochemically complex, diverse and adaptable. These minute masses of living matter, the microbes, are the main driving force of the biosphere today.

## Altruistic Genes

Certain animals, specially social insects, mammals and birds behave at times "altruistically". That is, they act in ways which may benefit other members of the same species while risking their own safety and thereby reducing their chances of reproduction. If we assume that such "altruistic" behaviour is wholly or partially sponsored by genes, it immediately gives rise to a paradox. For genetic behaviour, which reduces chances of reproduction, diminishes the expected number of similar genes in the next generation. It should, therefore, lead to their eventual extinction. On the other hand, if such behaviour is not influenced by genes, one may well wonder how it arises in the first instance and having arisen how it persists.

Deeper examination, however, shows that the paradox of "altruistic" genes is more apparent than real. For obviously close relatives have a certain proportion of genes in common. Therefore, a gene, which induces altruistic behaviour towards such relatives (specially siblings), will contribute towards the survival of similar genes in others it saves by its self-sacrifice. It will thus confer on evolutionary advantage on the species.

The above argument has recently been greatly refined to yield a mathematical theory of evolution of altruistic and co-operative behaviour within a single species in a book titled *The Genetics of Altruism* by Scott A. Boorman and Paul R. Levitt. Their theory broadly distinguishes three different patterns of "altruistic" behaviour. First is "reciprocity selection" in which an individual behaves altruistically towards all other members of the same species. Second is "kin selection" where altruism is restricted only to close relatives. Third is "group selection" in which the survival of a group is influenced by the proportion of different genotypes contained in it. The mathematical treatment of all three cases leads to one broad conclusion.

While it is not at all easy to establish a genetically determined cooperative or altruistic behaviour; once established it is very stable and persistent. It is, therefore, highly conducive to the survival of the species.

## Heredity and Blood

It was *vox populi* that Thackeray echoed when he made James Crawley in Vanity Fair say, "Nothing like blood, Sir, in horses, dogs and men." "*Vox populi* that Crawley echoed was not *vox dei* but voice of ancient prejudice that made blood — the blended blood of both parents — the carrier of heredity from parent to progeny. If it happened to be "noble", "royal" or "pure", the offspring would be brave, beautiful and brilliant. But if it was common, base or plebian, he would turn out to be criminal, ugly, shifty and depraved.

We now know better. Modern genetics has shown that it is not blood that passes from parent to progency but packets of genes called chromosomes. Blood is as much the outcome of the chain of biochemical reactions sparked by the inherited genes as any other tissue or organ of the body. Consequently even a mother and her child do not share a single drop of blood although she carries the fertilized ovum during its nine-month long gestation. Indeed, in some cases, she may even unwittingly kill the baby if her blood contains an hereditary "something", the so-called Rh factor, which is hostile to that in her baby's blood. It is just as possible for two persons in a family to inherit different kinds of blood as it is for them to inherit different eye colour or other physical traits. The reason is that the type of blood an individual inherits is like the colour of his skin or eye wholly genetical regardless of environment.

It happens that while the choice of eye or skin colour that the genes concerned sponsor is rather limited, that of blood types that the sponsoring genes provide is practically unlimited. The skin may be white, black, honey yellow, brown, mulatoo, or copper coloured. But the blood types are as numerous as the gentypes. The existence of 20 independent blood factors so far established — and many more have been detected or assumed to exist — the number of possible blood types is already $2^{20}$ or 1,048,576.

## Viral Interference and Human Interferons

Viral interference is the mechanism whereby the infection of an animal by a virus seems somehow to protect it against subsequent infection by another virus. It was discovered in the 1930s. Two decades later Alick Issacs and Jean Lindermann isolated an agent responsible for it. It was a protein released by cells exposed to a virus that enables other cells to resist viral infection. They called it interferon.

Not surprisingly interferon became instantly a drug of great promise. For the protein is not directed against any one virus but rather protects cells against a wide range of viruses. Besides being a wide spectrum anti-viral remedy, it was believed to have other therapeutic possibilities also because of its effect on a number of different activities of the body cells. Moreover, as a natural cell product it seemed to be safer than most new synthetic or experimental drugs.

Unfortunately, the great promise of interferon has not yet been redeemed. Its use as a cure for a wide diversity of viral diseases and cancers was bedevilled by new complexities and difficulties. They were of three main types. First, interferon was found to be not a single protein but a large number of proteins varying not only from species to species but also within a single species. Second, its mode of action proved to be indirect and is still not fully understood. Third, it is secreted by cells in minute quatities and was extremely difficult to purify so that it was hard to accumulate enough interferon for clinical trials.

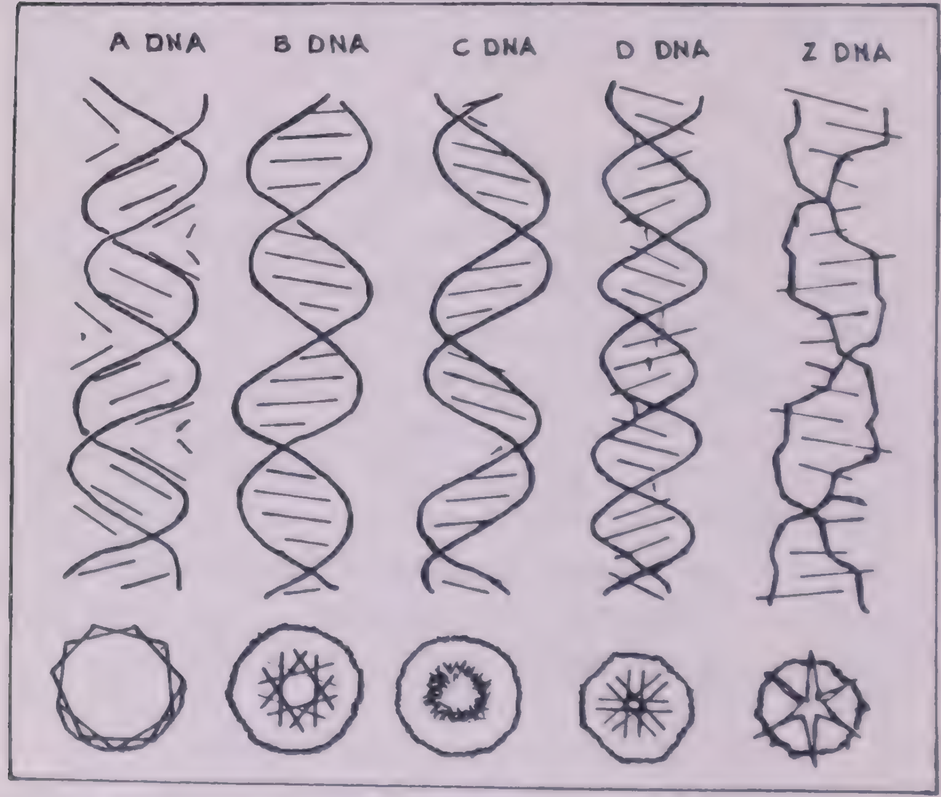
In the past few years some of these difficultie have been overcome or, at least, greatly mitigated b resort to the new recombinant DNA technology. I has led to the isolation of genes that produce huma interferon and their cloning or incorporation i bacteria like *E.Coli* found in the human gut. As a result it is now possible to produce in quantit recombinant human interferon by fermentation a well as to purify it by means of monoclonal antibodies. In fact, interferon is now being routinel manufactured by bacteria in a battery of 400 litre fermentation tanks at Hoffmen-La Roche, Inc. i the USA. Recombinant DNA carrying a gene fo human alpha interferon is inserted into the cells o bacteria *E.Coli.* These *E.Coli* cells are then grown i a culture medium. The bacteria proliferate synthesizing the human protein alpha interferon along with thousands of their own. When bacterial cells reach maximum concentration, they are killed, discharged from the fermentation tanks for concentration b centrifugation. The human alpha interferon is the extracted and purified for clinical trials.

The first trials to test dose levels of the manufactured interferon and ascertain its side effect on human beings began in 1981. The extensive test of interferons efficacy against viral diseases an cancers now under way seem to suggest that it ma soon be possible to tailor interferon molecules t cure paticular side effects like fever, chills, mino gestrointestinal upsets, muscle aches, fatigue and anorexia that followed in the wake of earlier use of rather crude interferon. For we are no longer limited to the set of natural interferons. We can not break up interferon genes and splice the pieces to make new genes to tailor interferon molecules to produce particular effects.

## The DNA Story

The starting point of molecular biology was the discovery of the structure of that macromolecule of life we call DNA (deoxyribonucleic acids). It led to a deeper understanding of the basic molecular machinery of life which is now being increasingly manipulated to "engineer" genes to serve our own ends. But despite some spectacular successes of "genetic engineering" techniques great mysteries still remain. The most intrigueing one of them is how a single fertilized egg cell develops into a being of over a trillin cells that do myriad different things while each cell contains all the genes. That is, how are genes controlled so that some are activated while others remain dormant.

One possible answer is that DNA is a dynamic molecule, which alters its fine structure and it is these alterations that play a crucial role in gene control. It has now acquired some credibility because of the recent discovery of a variety of DNA structures besides the conventional one that appears in all textbooks on the subject. It is a right handed double helix schematically shown as B-DNA in *Figure.* But we now know four other variants called



The structure of DNA as characterised by watson and crick (B-DNA) is only one of a number of possible forms that DNA can adopt. Although most natural DNA is in the B form, four others have been characterised. Z-DNA is a left-handed helix and there is mounting evidence that it might play an important role in the regulation of gene activity. A, B, C, D and Z-DNA are shown above in side and plan views.

A, C, D and Z-DNA. Of these four, the most interesting is the completely unconventional left-handed spiral Z-DNA. It was discovered in 1979 by Alexander Rich and his team when they were investigating the structure of small synthetic pieces of DNA using X-ray diffraction. It was then believed that Z-DNA was a synthetic freak and had nothing worthwhile to tell us about how natural DNA works in living cells.

As Rich did not share this belief, he proceeded to show that Z-DNA also is a natural product that works in living cells. He did succeed in showing that there are in the cell regions containing an appropriate Z-DNA forming sequence. But as the standard B-DNA structure is still the most stable under normal circumstances, it is not understood how this potential of the cell to make the unconventional Z-DNA is actualised.

So for Z-DNA to be accepted as relevant to normal biology, it was necessary to find a natural mechanism within cells that could push B-DNA into the Z-conformation. Several such mechanisms have now been suggested. But no one yet knows what is the function, if any, of the unconventional Z-DNA in gene control. Scientists are busy looking not merely into the significance of Z-DNA but also of several other variations on the double helix theme that Watson and Crick, both Nobel Laureates, first played nearly three decades ago. Since investigation into structural variations of DNA is the most active area of research in all biology now, we may know the answer to the "gene control" problem by the end of the century, if not, the decade.

## Sex and Death

Sex and Death are nature's inventions to evolve more advanced forms of life after its emergence on earth. It is now generally believed that the first live organism was a molecule of life combining both the functions of catalysis and self-replication. It appeared in the primeval oceans three to four billion years ago. Such an Adam molecule at birth found itself literally in a molecular garden of Eden where all the building blocks that its present-day successor organisms must work hard at synthesizing were available to it free. It could thus multiply pretty fast even though sexless and without an Eve! This primeval molecule of life was a single cell reproducing itself simply by splitting into two. The two new cells could not be said to be 'children' of the first, born the moment it died. For the two new cells were just parts of the first, split from each other when it reached a certain size and broke in half. It was thus both sexless and deathless (immortal).

However, because of its innate power of self-replication it continued to multiply until the accumulated supply of one of the intermediate components, say A, was exhausted—a molecular analogue of Malthusian pressure of population on the means of subsistence. It had no way of adjusting itself to its changed environment because of its remarkable property Jaques Monod has called invariant reproduction. That is, its ability to reproduce and to transmit *ne varieteur* the information corresponding its structure. As a result all its successors were *hi fi* replicas of itself as unable to adapt themselves to a new situation as their progenitor. But suppose it could produce a slight variant of itself capable of catalyzing the formation of the exhausted component A from some other protein precussor, say B, still present in abundance in the primeval oceans. It could then evolve into another more fit to survive in the new conditions of its habitat. Sex is nature's way of doing just that. It is tailor made to produce variants in such prolific abundance that some of them have almost cerainly a chance of survival no matter how the environment changed.

Sex produces differences between individual offsprings with the result that no two sexually produced organisms—except the rare freak identical twins—are ever exactly alike. Without sex there could have been no variety; without variety no evolution; without evolution no plants, vegetables and animals including ourselves. For the driving force of evolution—the survival of the fittest-demands that there should be differences between individuals. Because if all were identical there would be no fitter to survive, nor for that matter, unfitter to perish. Sex is, therefore, a *creative* departure from the *ne varieteur* mass self-replication of identical cells with which life made its debut on earth. Like all creations thriving on variety it is not without its uncertainty. It can produce as readily a masterpiece of lasting value as a malfunctioning monster fit for the scrap heap.

If sex by providing endless variety is one driving force of biological evolution, death is the other. Death is just as important as sex in the development of higher forms of life. As we have seen, sex is the originator of new and more complex models of life. Its inevitable corollory is the introduction of death to get rid of those grown obsolete, old and beyond repair.

## New Pathways in Antibiotic Research

The discovery of antibiotics in the 1940s was a remarkable achievement of modern medicine. But their further development now seems to have reached a blind alley. The problem is two-fold. First is the poor performance of classical antibiotics in patients whose own immune defences against disease are below par as is the case with premature babies, the elderly people who have had transplant surgery and the like. Second is the steady erosion of the efficacy of a number of antibiotics due to the emergence of new mutants or variants of bacteria immune to them. These problems have obliged some researchers to explore new ways to get round the blind alley facing them.

The classical antibiotic research is simply screening substances for antibiotic activity by tests designed to discover one that can kill a wide diversity of bacteria. The more it can kill the broader its spectrum and therefore the higher its rating as a drug of choice.

The new departure from this starting point is based on the perception that no antibiotic should be allowed to kill all bacteria. It should kill only enough of them to allow the body's own immune defences to mop up the rest. For body's own defence system produces specialised cells that also kill the invading bacteria. If these bacteria circulate freely in the body, they are an easy pray to both the body cells and their antibiotic ally. But if they manage to "hide" themselves inside target cells of the body, as for instance, tuberculosis bacteria do by entering tissue cells, they are in a very sheltered position. Again if they manage to wear, so to speak, a mask, they can evade recognition as enemies by the body's immune cells. Some bacteria such as those which cause sore throat, scarlet and rheumatic fevers do so by developing a protein coating on their surface known as M protein thereby covering their tell-tale surface structures hidden under the M protein coat that enables the body's immune cells to recognise them.

Some bacteria have learnt another ruse. They produce toxins that undermine the body's defence. Yet others have evolved into new mutants that are able to resist the antibiotics that were effective against their earlier progenitors.

It has now been suggested that the clues to the solution of these and allied problems may be found by a new twist in antibiotic research. That is, we should investigate a hitherto neglected area, namely, the impact of antibiotics on the way bacteria and the body's immune system interact. For instance, it has been known for almost 10 years that antibiotics can alter the shape of bacteria. Yet no one has examined the possibility of availing of these effects to promote therapy. Dr. Curtis Gemmel of the Royal Infirmary in Glasgow, Scotland, has begun to do exactly that. He has recently used doses of antibiotics sufficient to alter a bug's shape but not lethal enough to kill it off. The idea is to see how well a particular type of body's immune cell can by itself finish off the still alive bug of altered shape. He claims to have obtained some promising results. It seems that pre-treatment of some bacteria by small doses of antibiotic alters their structure in a manner that facilitates greatly their recognition by the body's immune cells.

Another approach to the problem is to search for antibiotics which are capable of penetrating into cells to search out bacteria lurking within. A case in point is the antibiotic rifampicin. It owes its efficacy in tuberculosis treatment to its capacity to penetrate target cells, in particular, those in lung tissue. Professor Charles Easmon of the Wright Fleming Institute at St. Mary's Hospital in London has been investigating refampicin derivatives to see which are most potent in this respect.

In sum, the new antibiotic research aims at using antibiotics more sparingly as aids to body's immune responses rather than as outright killers. This increased reliance on the body's immune response is also expected to diminish the probability of the emergence of new antibiotic resisting mutants of bugs.

## Cancer

Cancer is the uncontrolled proliferation of cells which is just about beginning to be understood. The recent discovery of a peculiar type gene called *oncogene* is a first step towards such an understanding. Ordinary genes in human cells have a function in normal metabolism. But there are some which besides performing this function, can be triggered to promote cancerous growth. The discovery of such oncogenes has provided both a conceptual framework and a set of powerful tools for investigating the molecular genetics, of cancer. A number of lines of research have now begun to make sense of what had seemed to be disparate observations concerning the causes and manifestation of malignancy.

One line of research has recently led to the discovery that the *sis* oncogene encodes a protein similar or identical to a growth factor given the code name PDGF. Now those human tumours found to express the cellular homologue of the *sis* gene are sarcomas and gliomas derived from cell types sensitive to PDGF. It therefore seems that the oncogene enzymes throw a switch that commits cells to uncontrolled proliferation.

The mechanism that activates such an ocegenetic switch is apparently central to growth control. and the production of aberrant growth factors like PDGF, may well be a necessary prelude to cancer cure.

## The Cycle of Seasons and Ice Ages

The seasonal variations of global temperature are the effect of changes in the solar energy received by the earth. These changes arise because of periodic shifts in the orientation of the earth relative to the sun as well as its distance from the sun. If the earth's orbit round the sun had been perfectly circular and its orbital plane had coincided with the earth's equitorial plane, both its distance and orientation would have remained the same all the year round. As a result there would have been no change in the global insolation received from the sun at any latitude and hence no cycle of the seasons. Actually the plane of the earth's orbit round the sun, the ecliptic, does not coincide with its equitorial plane. The angle between them called obliquity is about 23.5 degrees now. Because of this inclination the Northern Hemispher points to the sun during June, July and August and receives more sunlight than it would have if the two planes were coincident. For the same reason the Southern Hemisphere receives less sunlight than it would have in the absence of obliquity. The situation is reversed six months later when the earth makes a U-turn in its orbit. The obliquity of the ecliptic is therefore the main cause of the periodic changes in solar insolation and hence of the cycle of seasons.

Another factor affecting the seasons cycle is the variation in the earth's distance from the sun because its orbit is an ellipse. Because of the earth's orbital eccentricity its distance from the sun varies with the time of the year. It is closest to the sun in January and farthest in July. Accordingly the global insolation is slightly greater in January than it is in July. The upshot is that the Northern Hemisphere has warmer winters and cooler summers than they would have been otherwise.

The cycle of seasons we experience every year is thus due to the obliquity and eccentricity of the earth's orbit. Both these orbital parameters, however, slowly change with time as a result of the gravitational perturbations of the moon and other planets. The nearly periodic changes caused by such perturbations during the past several hundred thousand years have been calculated with great precision. These calculations show that the earth's orbital obliquity varies between 22.1 and 24.5 degree with a period of 40,000 years, while its eccentricity or deviation from circularity, varies between .005 and .06 with a period of around 100,000 years. The third parameter of earth's motion that also varies periodically is the precession of the axis round which it spins daily like a gargatuan top. This is merely to say that the direction of its axis slowly describes a circle on the celestial sphere with respect to the fixed background of distant stars in a period of about 26,000 years.

The periodic variations of the three parameters of earth's motion—the obliquity and eccentricity of its orbit and the precession of its axis of diurnal rotation are believed to be the prime cause of those ultra slow change in the incoming solar energy which switch on or off the global ice ages. The idea that ice ages come and go every now and then was first mooted in the nineteenth century when growing geological evidence seemed to show that the last ice age on earth ended some 18,000 years ago. The evidence collected so far indicates that one third of the land surface of the earth was then covered with ice. The ice sheets were several kilometres thick locking up so much of oceanic water that the sea level was almost 100 metres lower than it is now.

It is now believed that the glaciation of 18,000 years ago was the last of the ten ice ages in the past million years. The ice ages, therefore, appear to recur every 100,000 years. This periodicity of their recurrene is also the periodicity of the variation of earth's eccentricity, one of the three parameters that effect the solar insolation received by the earth. Unfortunately, its contribution to solar insolation is much less than that of the other two parameters, namely, obliquity and precession. These two major contributors have much smaller periods—only 40,000 and 26,000 years respectively. It is possible that the climate system composed of the atmosphere, the oceans, the continents and the ice sheets, may have a natural preferred frequency of oscillation with a period of 100,000 years. Eccentricity may change solar insolation less than obliquity or precession does, but the changes induced by its variations may be more effective in driving the climate because they have a frequency near the natural frequency of the system. If so, the recurrence of the ice ages with the periodicity of around 100,000 years may will be due to resonance, a property of many physical systems.

## The Theory of Plate Tectonics

According to this theory the earth's lithosphere, its outer crust, is made up of several layers of relatively thin (about 100 kilometre thick) tectonic plates laid one upon another. These plates are constantly in slow motion with respect to one another. This motion of tectonic plates is the main driving force of those natural geological processes that lead to the formation of continents and ocean beds, mountain ranges, rift valleys, diverse land features, and continental drift. They are also responsible for volcanism, earthquakes and other similar violent phenomena. All of them are caused by faulting, folding or disruption of rock strata. Rocks suddenly disrupt or fracture when the strain to which they are subject exceeds their strength.

Consider, for the sake of definiteness, the occurrence of earthquakes. Since the rocks of the tectonic plates are elastic, they can store mechanical energy exactly as it is stored in a compressed spring. When two adjacent plates move by a small amount, the motion elastically strains the rocks on both sides of the plate boundary technically called a 'fault'. When the stress exceeds the frictional strength of the fault, the frictional bond snaps at its weakest point. That point of initial rupture, called the hypocentre, may be near the surface or deep below. From the hypocentre the rupture rapidly propagates along the surface of the fault, causing the rocks on its opposite sides to begin to slip past each other. A portion of the frictional stress the rocks had exerted on each other before the rupture is suddenly and violently released, the rocks along the fault rebound, or spring back, to an equilibrium position in a matter of seconds. The elastic energy stored in the rocks is released on rebound as heat generated by friction and as seismic waves. The seismic waves radiate from the hypocentre in all directions producing an earthquake. The point on the surface above the hypocentre is the epicentre of the earthquake.

In some cases the rocks rebound not in a period of seconds but over an interval of minutes, days or even years. The seismic energy radiated at any one time is then quite small. This slow process is known as seismic slip or creep. We still do not fully understand why seismic energy is released violently in some cases and more sedately in others.

## Seismology

The seismology waves that faulting rocks on rebound radiate are of two main types: body waves and surface waves. Body waves travel through the body of the earth. The fastest are called primary (P) waves, which like sound are compression waves capable of propagating through both solid and liquid rock. They are, in fact, *sound* waves in earth although their frequency of vibration is mostly well below the range of audible sound. The slower body waves (secondary or S waves) are, transverse shear waves that can travel through solid but not liquid rock. Surface waves travel around the surface of the earth with velocities that are generally slower than those of P and S waves. Two kinds of surface waves predominate; Rayleigh waves, which have motions in the vertical plane aligned in the direction of travel, and Love waves which have only horizontal shear motions. At considerable distances from the earthquake source or, hypocentre, P, S, Love and Rayleigh waves separate from one another reasonably clearly because of the wide diversity of their speed of propagation. But near the source they are usually mixed in complicated ways.

The core of seismic methodology is the analysis of seismic waves radiated from an earthquake focus or hypocentre and recorded on arrival at earth's surface by specially contrived instruments or detectors located there. In some kinds of work as many as 36 detectors may be set up along a profile line only a few hundred feet long to record the energy sent out by an artificial mini-earthquake caused by a chemical or nuclear explosion. The detectors are connected by wire to amplifiers and a recording camera, often placed in a specially designed truck. The vibrations received by the detectors are recorded on rapidly moving photographic paper and a timing device mutually a tuning fork, marks every hundredth of a second. These instruments enable the measurement of various parameters of seismic waves like their spread or amplitude, frequency, speed, etc.

The main problem in reading seismograms is the variable and, in places, complicated structure of the earth. As a result the seismic waves that are produced at a seismic source are distorted during their passage to the recording instrument in the surface. Further distortions occur from the response of the instrument itself. Thus, to disentangle the instrument wiggles on the seismogram the three factors – source properties, propagation and instrumental properties – have to be considered before its message can be deciphered. This is no simple matter.

## Measuring Earthquake Fury

The fury of an earthquake is measured by the energy it releases. The Unit of measurement is called magnitude on the Richter scale. On this scale a barely perceptible earth tremor is assigned zero magnitude and a catastrophic one a magnitude of 6 to 7. The upper limit seems to be 9 as no earthquake has been observed to exceed a magnitude of 8.9.

The magnitude scale is basically multiplicative, or logarithmic with base ten, unlike the commonly used *additive* scale for measuring weights and volumes. This is merely to say that an increase of magnitude by one unit corresponds to a *tenfold* increase in the energy released. Consequently an earthquake of magnitude 8 would be 10,000 times larger than one of magnitude of 4.

Besides the magnitude of an earthquake which is a measure of its *intrinsic* fury, there is another measure of its *local* violence at any given place. It is called its intensity. Intensity is like the *apparent* luminosity of a star (or candle) when viewed from a certain place as against its intrinsic or absolute luminosity which remains the same no matter from where it is viewed. Intensity of an earthquake, therefore, like the apparent luminosity of a star varies from place to place depending on the distance of the point of observation from the epicentre of the earthquake and local geological conditions. It is a qualitative (and the oldest) way of measuring the local violence of an earthquake by observing the effects of the shaking on the ground, on the people and on structures.

The intensity scale varies from I to XII. The imaginary line joining points of equal earthquake intensity are called iso-seismals. For each earthquake one can draw iso-seismals. They are useful to planners, insurance companies and others engaged in rescue operations as they help in estimating the damage in an area.

## Dilatancy Theory

A recent breakthrough in thinking about the problem of earthquake prediction is the emergence of dilatancy theory. Dilatancy is the name given to the phenomenon discovered in the laboratory experiments with rocks about two decades ago. When a rock is squeezed, it deforms and eventually fractures. Just before the fracture it swells owing to the opening and extension of tiny cracks. This inelastic extension or increase in volume called dilatancy begins when the stress reaches about half the breaking strength of the rock.

This property of rocks to swell or become dilatant when the stress is *half* the fracture value is an important attribute. It is now being increasingly availed of to predict earthquakes scientifically rather than sooth sayingly. For when rocks become dilatant, other measurable attributes change like, for example, their electrical resistance and the propagation speed of elastic (or seismic) waves travelling through them. The idea is to detect these physical changes in a region of the earth's crust that has become dilatant just before the onset of an earthquake and issue an "early warning". The snag is that for a great earthquake some of these precursory changes can begin to occur 10 to 15 years before the actual shock. There are, however, other changes such as a reduction in the number of small tremors, followed by a rapid increase, which can occur days or hours before the shock. They can therefore serve as a pointer to evacuation of weak structures, closure of nuclear power plants, gas lines and similar last-ditch precautions.

It is true that the dilatancy or diffusion theory of earthquakes is still in a very rudimentary state. Nevertheless, it is a beginning in the right direction because it is widely held to provide a physical basis for the group of precursory phenomena, that presage earthquakes. It is on its basis that the Chinese siesmologists were able to predict the Liaoning (Haicheng) earthquake of 1975 well before its actual occurrence, so that people were evacuated and lives saved. A notable failure was the unpredicted 1976 Tangshang earthquake near Peking, which is reported to have killed 650,000 people. Earthquakes prediction methods adopted by the Chinese involve a heterogeneous mixture of indicators both instrumental as well as of a more homely nature like the behaviour of animals collected on a regional basis being a valuable adjunct to the more usual measurements of seismic velocities, changes in the magnetic field, hydrological indications and so on. In the long run scientists can hope predict earthquakes as reliably, at least in the short run, as weather presently.

## Mohorovicic Discontinuity

Our earth is not the *terre firma* that the phrase seems to imply. It consists of three main parts. There is the inner core that is mostly liquid with perhaps small solid nucleus at the centre. Surrounding the core is the mantle which in turn is surrounded by its outer crust geologists call lithosphere. Mohorovicic discontinuity, or Moho for short, is the seismic discontinuity at an average depth of 30 kilometre that represents the interface between the earth's crust and mantle.

It was originally discovered by the Croatian geologist Andrija Mohorovicic who found that seismic waves from a Serbian earthquake arrived quicker at certain stations (beyond about 1100 kilometres distant from the source) than they should have. He concluded that the waves in accurate paths had entered suddenly a zone of higher velocity and therefore arrived sooner than could have been predicted. He called the zone a discontinuity between the inner mantle and outer crust. He determined that the depth of the discontinuity varies from 5 kilometres under the oceans to 20 kilometres under the Andes mountains with an average depth of 50 kilometres under continental Europe.

## Volcanoes

A Volcano is a place where molten rock and gas (magma) erupt on to the surface of the earth. The mountain or hill formed by the eruptive debris is also often called a volcano. Over 500 volcanoes are known to have erupted during the past 500 years killing over 200,000 people.

Volcanic eruptions are obviously small surface manifestations of great subterranean turmoils going on deep below in the earth's interior. We have just begun to gather some clues to what may be happening in the bowels of our earth, the root cause of its volcanic belchings.

Some regions of the earth's outer crust at depths of 100 kilometres or less have an extremely hot shell of glassy or crystalline material. This solid material bcomes liquid if the pressure on it is reduced or its temperature rises. The pressure may reduced by the bending or cracking of the rocks lying above it; the temperature may be raised by radioactive decay of materials in earth's interior. In either case the liquified material forms a fluid mass, called magma. Now magma is lighter than the overlying rocks so that it tends to rise wherever it finds an outlet. If there are fractures in the rock that let it rise directly to the surface of the earth, it comes out quietly as a flood of fluid lava. Sometimes it reaches surface. In that case it may spread sideways and form a reservoir of hot magma that erupts into one or more vigorous spasms wherever and whenever it finds cracks in the roof.

Although disturbances of the earth in regions of mountain building produce conditions favourable to formation of molten magma and its escape to the surface, not all young mountains have volcanoes. The two notable exceptions are the Himalayas and the Alps. Both show no volcanic activity.

Since ancient times volcanic eruptions have terrified mankind even more than earthquakes because of the catastrophic disruptions of the earth's surface that follow in their wake. But it is an ill wind that blows no one any good. The volcanoes have provided some of the world's richese soils and some of our magnificent scenery. Even more important, they and their attendent hot springs and gas vents have also been supplying, throughout geologic ages, the oceans with water and the atmosphere with carbon dioxide. They have thus provided the wherewithals of plant life on earth without which there would have been no animal life either including ourselves, verily they are the birth pangs of primeval life on earth.

## Artificial Intelligence

Artificial Intelligence (AI) is an attempt to make machines which amplify our *cerebral* power exactly as a diesel engine amplifies our *muscle* power. They are designed to emulate human mental faculties such as language, memory, reasoning, common sense, speech, vision, perception and the like. We are still far from making them despite the recent spectacular advances in computer technology. The reason is that human intelligence has not yet been sufficiently introspective to know itself. When at last we have discovered the physical structures and neurophysiological principles underlying the intelligence shown by a living brain, we shall have also acquired the means of simulating it synthetically.

What we have done so far is to make a very crude simulation of the living brain by assembling simple neural substitutes of digital kind like on-and-off mini-switches called transistors or silicon chips. As a result the comparison of networks of electrical hardware we call computers and of biological neurons we call animal brains is our most puzzling paradox. Though they are as closely allied in some respects as next-of-kin, in others they are as far apart as stars and sputniks.

Consider, to start with, the resemblances. In performing a mental task, both resort to three principles—of *choice* to decide the future course of action, of *feedback* to self-rectify errors, and of *redundancy* in coding as well as in components to secure *reliability.* These resemblances at first encounter appeared so striking as to earn the computers the nickname of electronic brains. But we now know better. Alas! the divergences diverge much more radically than the coincidence coincide. The most conspicuous departure is in respect of methods of *storage, recall* and *processing* of information. Because the methods of data storage, access and processing practised in computer engineering today are very primitive vis-a-vis their infinitely more complex but unknown analogues of the living brain the computer has not yet come of age to wean itself away from the tutelage of algorisms. That is, it can only handle such tasks as can be performed by a more or less slavish follow-up of prescribed routines The living brain, on the contrary, operates essentially by non-algorismic methods bearing little resemblance to the familiar rules of logic and mathematics built into the computer.

It seems that the language of the brain is logically much "simpler" than any we have been able to devise so far. As von Neumann once remarked we are hardly in a position even to talk about it much less to theorize about it. We have not yet been able to map out the activities of the human brain in sufficient detail to serve as a foothold for such an exercise. For too long we have been content with the superficial analogy between the living brain and digital computers merely because both are hard wired networks wherein information is transmitted as digitally coded electrical signals. But in the living brain further transmission of information across the synapses (junctions of neurons), is no longer digital It is not all-or-nothing response as it is in computers It is finely graded response secured by subtl controlled release of neurotransmitters, neurochemicals, which have fast but brief effects on ver limited targets. In the past ten years it has bee realised that an enormous number of substances ar involved in synaptic communication deftly modulating the transmission process. These substances are c two kinds—neutrotransmitters and neuromodulators.

Unlike the fast transmitters, most of the neuromodulators are slow acting, long lasting and often work at long range in very complex ways. Their discovery has given rise to a new concept of the nervous system as an array of hard-wired circuits constantly tuned by chemical signals totally unlike our telephone exchanges or computers. It is this chemical modulation that gives the living brain its flexibility and adaptability to long-term changes both internal and environmental. Recent research has revealed two main points of departure between the computer and the brain. First, the basis of the latter's long-term memory is very unlike that of the computer. It seems to be the result of changes in protein synthesis brought about by neuromodulators. They do so by producing permanent changes at synapses and by regulating receptor density, which might alter a neuron's sensitivity to transmitters. Second, we have to study the living brain at three different levels — the molecular, cellular and organismic. Unfortunately it is very difficult to switch from one level to another Thus it is very hard to link studies of the molecular constituents of memberanes, for example, to whole animal behaviour. The more we see of one level the more we block the view of others.

As a result AI research seems to have now reached a blind alley. It cannot make a breakthroug by doing more of the same. It will take long to lea out of it. For we are yet very far from completing th ever-increasing catalogue of neuroactive substance modulating the signals at synapses let alone unravel ing the complexity of their actions. It alone is like to provide the unifying factor so far lacking neurobiology. Its provision is the open sesame to A

## Heuristics

There are a number of non-computational tas like writing poetry, composing music, recognisi patterns, proving theorems, etc which the comput is as yet unable to handle. Although in these case too, problem solving processes or algorithm routines can be devised, they offer no guarantees success. Consider, for example, Swift's Laga routine for writing "books on philosophy, poet politics and so on" described at length in Gullivers Travels. No computer, however, rap could follow it through to success simply because t number of possible solutions that the routine gen ates rises exponentially. It is the same with all oth complex problems such as playing games, provi theorems, recognizing patterns, and the like, wh we may be able to devise a recursive routine generate possible solutions and a procedure to t them. The search fails because of the overwhelming bulk of eligible solutions that have to be scanned for test.

The only way to solve such non-algorithmic problems by mechanical means is to find some way of reducing ruthlessly the bulk of possibilities under whose debris the solution is buried. Any device, strategem, trick, simplification, or rule of thumb that does so is called a heuristic. For example, printing on top of every page of a dictionary the first and last word appearing there is a simple heuristic device which greatly lightens the labour of looking for the word we need. "Assume the answer to be X and then proceed backwards to obtain an algebraic equation" is another instance of heuristics for divining arithmetical riddles like those listed in the Palatine Anthology or Bhaskara's Lilawati, Drawing a diagram in geometry and playing trumps in bridge "when in doubt" are other instances of heuristic devices that often succeed. In general, by limiting drastically the area of search, heuristics ensure that the search does terminate in a solution most of the time even though there is no guarantee that the solution will be optimal.

Indeed, a heuristic search may fail altogether. For by casting aside a wide range of possibilities as useless. Consequently a certain risk of partial failure, such as sometime missing the optimal solution, or even of total failure in a heuristic search has to b faced, nevertheless, resort to heuristics for solvin problems more complex than computation and n emenable to algorithmic routines is inescapable.

## Algorithms

Algorithm is a repetitive routine which, followed, is guaranteed to solve a problem assumin of course, that the problem has a solution. A example is that of the simple routine for searching word in a dictionary. One scans the list of words i alphabetical order till one finds it. The dictionar provides a set of possible solutions in some order an we test each word in succession till the required on is found. A more recondite example is the iterati scheme for calculating the square root of any numb N. This scheme yields a more exact approximati $x_i+1$ from a less exact one $x_i$ by recourse to th formula $x_i+1=\frac{1}{2}(x_i+\frac{N}{x_i})$ suppose we require th square root of N=4. We know of course, that it is But if we did not know it and made any wild guess b taking the first approximation x as, say 4, then o formula provides a much closer second approxim tion $x_2=2.5$. From $x_2=2.5$ we may obtain a st better third approximation $x_3=2.05$ by a seco application of the same formula. A third applicati yields a yet closer approximation($x_4$) equal to 2, t required square root of 4.

Both algorithms of our illustration are typical of any problem solving process. There is a generator that produces possible solutions – the word list in one case and the iterative formula in the other – with a test procedure for recognising the solutions. In both cases the search is guaranteed to succeed in reasonable time such as we can afford. Both processes are, therefore, amenable to computer operation even though the word search in a list involves handling non-numerical symbols as the computer can manipulate them as readily as numbers. Therefore all that need be done is to programme the computer to follow the prescribed algorithm or recursive routine of scanning possible solutions produced by the generator process, test them in succession and terminate the operation when the solution is in hand.

The computer owes its success in accomplishing such computational or algorithmic tasks to its high speed operation, so that so long as some way of performing a task can be specified it does not really matter how laborious is the ensemble of operations if carried out by us humans.

It is the lightning repidtly of computer operation that makes even its most devious computational roundabouts quicker than many an apparent crow flight.

# Quantum Computer

The first giant computer ENIAC made around forty years ago was an assembly of 18,000 on-and-off switches called vacuum tubes. It weighed 30 tons and gobbled 150 kilowatts of power, a formidable pack for the storage of only 700 "bits" of information in its memory. Since then computer technology has advanced greatly by increasing miniaturization of its basic unit, the vacuum tube. It was first replaced by the ubiquitous transistor and now by the silicon chip. But even a silicon chip is by no means the ultimate in miniaturization. Thanks to superconductivity of certain materials, whose electrical resistance vanishes completely at temperatures close to absolute zero, or 273°C below freezing point of water, it has been possible to make a 1000-fold more compact device called croyotron. An idea of the relative compactness of these computer devices may be had by their packing densities. A cubic foot of space which could barely house a few hundred vacuum tubes could comfortably accommodate a few thousand transistors, several hundred thousand silicon chips and some millions of croyotrons.

Computer hardware engineers hope soon to cross even the croyotron limit of miniaturization. They believe that the 'quantization' of magnetic flux as within the closed loops of superconducting croyotrons, will one day be the basis of a new memory storage unit. A quantum computer is merely an assembly of such quantal units, the ultimate in miniaturization. Since the scale of the most tightly packed electronic computers today is measured in some hundreds of interatomic distances, the quantum computer of the future will be a million times more compact for any given storage capacity of its memory.

The question that arises now is this. To what extent the deterministic uncertainty of quantum mechanics will affect the performance of such a quantum computer. For when the linear dimension of its memory storage unit strinks from its present molar scale to the microscale of *single* interatomic distance, the indeterminacy principle of quantum mechanics must determine the limits to the accuracy of its computation. What are these limits?

This question was considered for ordinary computers by the English logician, A.M. Turing, about fifty years ago. He sketched the design of a computing machine since called the Turing machine to assert that it could compute anything generally held to be computable. A Turing machine is merely a stripped-down computer, consisting only of an indefinitely long memory tape and a device we now call a processor, whose state at any instant depends on its previous state and on the most recently read item of information on the tape. On the assumption that the information on the tape includes what we now call the programme and input data, the value of the machine is to demonstrate the power and limitations of the computing process.

The concept of the Turing machine as a demonstration of what might be computable has now been overtaken by the still more idealized quantum computer. Dr D. Deutsch from the Department of Astrophysics at the University of Oxford has recently shown that quantum computers are potentially more powerful in important ways than even a Turing machine, the machine that computes anything that is computable. A quantum computer can carry out any computation which a Turing machine can perform. But because the elementary unitary transformation can mix together quantum states in ways that have no classical analogues, the universal quantum computer can yield results beyond the range of ordinary machines. For example, a quantum computer should be capable of generating true random numbers and not merely their fake simultations as ordinary computers do. As D.E. Kruth has shown in The Art of Computer Programming, programmes purporting to yield random numbers at the push of a button cannot be trusted.

Unfortunately, a quntum computer has drawbacks of its own. For example, to make this non-existent machine work, it is necessary to "tailor" its initial state in the sense of quantum mechanics. But it seems that such a state cannot be reached in finite time!

## What is Software?

Software is the intangible 'ghost' in the computer machine that makes it tick. The digital computer is merely an assembly of transistors, or, their more miniature counterparts, the silicon chips, each of which is capable of assuming only two states either on or off, by adding or removing an electric charge. Now 'on' and 'off' can be interpreted in two distinct ways. It can be used both for writing numbers as well as enabling the machine to choose between two alternatives open to it at each contingency that may arise during the course of the computation. If we represent the 'off' position by the symbol 0 and 'on' position by 1, a relay of transistors in the computer memory can represent a number in the binary notation. For example, number 2, which in binary notation is 10, can be represented by keeping one transistor 'on' and the adjacent one 'off'. Likewise, if during the course of computation the machine is to decide whether or not to perform an operation, the operation 'proceed' can be denoted by 1 and its 'stoppage' by 0. Thus both numbers and logic of their manipulation can be written in the binary notation of two symbols 0 and 1 that is readily embodied in a transistor. Further, the fundamental rules of any arithmetical calaculation, namely, addition (which includes its inverse subtraction) and division (or its inverse division) are formally identical with those of the logical calculus (Boolean algebra) underlying the machine's decision-making process. It is because of this formal identity that the apparatus designed to mechanise computation is also able to mechanise acts of logical choices, that is, decisions.

Software then is merely the programme of instructions written in the binary alphabet of two letters 0 and 1 that tells the machine how to peform each step of the computation. It is compared in two major steps. First, the computer task is formulated in a flow chart specifying each step of the computation from start to finish. It is then translated in the binary language of the machine. The machine is then able to follow it because the binary programme of 0's and 1's is readily translated into the on-and-off language the computer understands. A computer programme in this basic language of the machine is, therefore, merely a write-up of an enormous numbers of zeros and ones in a precise order. The problem here is not the determination of the precise order. It is determined by merely following a prescribed routine. The problem is to replicate the billions of zeros and ones churned up by the routine in the right order without a *single* mistake.

The coded programme is in the basic "machine language", while the original programme in its flow-chart form is said to be in a "problem-oriented language". A wide variety of problem-oriented languages has been developed, making the process of successful programming depend more on understanding of the problem rather than on that of the computer on which it is run. Indeed, most of these languages are essentially machine-independent and can be used with any computer for which appropriate translation programmes exist. Its translation into the basic machine language, however, is a tedious and exceedingly error-prone. What is worse is that a programme written in machine code for a computer using one kind of processor has to be rewritten to run on a computer using a different processor.

To overcome these and other inadequacies of the basic machine code or language, numerous kinds of machine languages have been devised. As a first step, programmers tried to escape the tedium of machine code by replacing the unmanageable binary digits with mnemonics and symbols to specify operations and memory addresses. Programmes written in this way are called assembly languages. Originally these assembly languages were translated into machine code manually. But now their mnemonic instructions are translated into machine code by automatic programmes called assemblers. Programmers have also devised still more sophisticated languages like IBM's FORTRAN, ALGOL, JOVIAL, COBOL, and the like to mitigate the tedium of programming.

The invention of such sophisticated programming languages has vastly accelerated the turnout of the software industry. Without them it would have been impossible to meet the rising demand. The demand is still rising much faster than supply. Our own intended leap into the *hi tech* society envisaged by the Prime Minister for 2000 AD will require millions of lines of new software for its implementation, not to speak of the plans of other advanced countries like the implementation of the "star wars" programme of America. To meet it, programmes are:

a) avidly searching ways of reusing old machine codes in new applications;
b) relying more and more on computer power to automate programming;
and c) inventing still more sophsticated languages. Such languages are indeed themselves forms of automation.

# Measuring Intelligence

The great confusion of todays debates on the nature of human intelligence largely stems from the Kelvin doctrine, that you can measure something only when you really know anything about it. But it would be nearer truth to say that only when you really know something about it ought you to risk trying to measure it. For without prior knowledge of what to measure one is better off without measurement which, if attempted, is apt to degenerate into psuedo-quantification. Such psuedo-quantifications are hazardous because as soon as you have somehow assigned it the form of numbers, anyone can play with them. And if you are, in fact, not measuring what you are claiming to, any conclusion from the measurement may be dangerously wrong.

This quandary of the intelligence testers could have been escaped if some agreement had been reached on the nature of intelligence that the testers wanted to measure. But as the tests were devised in the absence of any such agreement, intelligence for them "simply became what the tests tested for," as E.G. Boring pointed out over 60 years ago. The consequential self-stultifying circularity of the tests is the main cause of the unhappy bewilderment even among the testers themselves as to the meaning of the tests. Some are completely satisfied with them in the belief that they are precise scientific measuring instruments. Others regard them as no more than mere aids to forming loose judgements of some sort. Still others recognising its multidimensional aspects fractionate it into better defined sub-skills.

J. P. Guilford, for example, theoretically distinguished as many as 120 highly specific abilities through a cross-classification of congnitive (knowing) activities into logically discernible processes such as remembering, divergent thinking, etc. In view of such an immense plethora of aspects of intelligence as the work of Guilford and others has recently revealed, it is futile to look for a satisfactory definition of intelligence. It is obviously too complex to be trapped in a succint verbal net.

Now the question is — what is intelligence? — is not answerable? We may as well ask instead a related question — what does it do for us? Two recent theories — statistical decision theory and information theory — provide some clues to a plausible simple answer. Statistical decision theory is concerned with drawing reliable conclusions under uncertainty due to available information being incomplete. Information theory, on the other hand, is concerned with segregating signal from its accompanying noise, that is, any distortion vitiating it during its transmission. One way of doing so is to avail of an important property of language called redundancy. It is this redundancy — surplus information — that makes language intelligible in the midst of noise. But for its existence, we could never solve a crossword puzzle, which after all is a deliberate mutilation of otherwise intelligible words by the poser to enable the solver to guess them. Such guesses succeed because of a correlation and link between successive letters of the alphabet. Since correlation and linkage imply orderliness of some sort, the higher the correlation, orderliness or redundancy the greater the chance of making the right guess.

Both decision and information theories, therefore, are problem-solving techniques by good guesswork. Decision theory improves the efficiency of guesswork by optimal use of incomplete information via probability calculus. Information theory does it by other means — the discovery of unexpected orderliness in the information provided. These considerations of decision and information theories have suggested a neat answer to our question — what does intelligence do for us?

The short answer is that it enables us to guess right and discover hidden linkages or orderliness. The two tasks are, indeed, complimentary in that discovering order is an important way of improving one's guesswork. Having understood what intelligence does for us, the next and more difficult problem is to understand how does it do so? No easy answer seems round the corner.

## Evolution of Galaxies

One of the unsolved problems of cosmology is the discovery of processes leading to the formation of galaxies and globular chasters, the largest structures in the universe, we observe today. From a study of these structures, we can infer that the initial chemical composition of the matter from which the first generation of their stars began was three-quarters hydrogen and one-quarter helium. The inference is derived from the theory of nuclear reactions which is reliable enough to enable us to make those miniature suns we call hydrogen bombs. Cosmologists have used it to postdiet the nuclear reactions that would have occurred in the early universe as it originated from the primeval Big Bang of about ten billion years ago.

Their extrapolation backward in time covers a period when the universe was barely one ten-billionth of a second to a few hundred thousand years old. At the earlier instant the whole of universe we see today was contained in a sphere smaller than our present solar system and its ambient temperature was around a million billion degrees. As it expanded, it cooled within three minutes to about one billion degrees. It was now a million-fold 'cooler' – cool enough to permit complex atomic nuclei of hydrogen and helium formed to hold together without breaking into smitherees. It took a few hundred thousand years for its temperature to drop to 3000 degrees, half that of the sun's surface today. The hot gas of hydrogen and helium with which the universe was then filled emitted radio noise. The noise has cooled since into a faint whisper we can hear to-day. It is the universal black body 3.5 cm microwave radiation first observed by Penzias and Wilson nearly two decades ago. The intensity of this universal extragalactic radio whisper is amazingly uniform across the sky. It is an indication that at the time of its emission, when the universe was a few thousand years old, there were no stars or galaxies or quasers. Their presence would have gravely heterogenized the primeval emission. We still do not know how the primeval hydrogen and helium that then filled the universe condensed into galaxies and globular clusters of to-day.

There were reasons to believe that the seeds of their formation were laid just before the universe was barely one ten billionth of a second old. At that remote instant in the past the matter of the universe went through what is called a "phase transition", like the freezing of water into ice. The analogy though remote is real enough. For when water freezes into ice, the spatial symmetry of liquid water is broken The fundamental symmetry between different kinds of elementary particles forces in its nascent state was broken in an analogous manner. We do not yet know precisely at what temperature this important phase transition occurred, or which of several proposed mechanisms for transition is the correct one.

W.H. Zurek has recently suggested a laboratory experiment whose outcome might reveal the nature of the unknown mechanism of this cosmic “phase transition”. The proposed experiment is simply to rapidly pressure quench a sample of helium in an annular container to take it quickly through the transition from normal to superfluid state. Zurek predicts that the sample will acquire a random non-zero rotational velocity which should be readily measurable. If observed, it will go a long way to clarify our ideas of primeval phase transition.

It will tell us if it can generate various topolog callystable “defects” such as monopoles, domai walls and, in particular, ‘strings’ which are cosmi versions of the quantized vortex filaments in supe fluid helium or the flux of tubes in superconductor It was suggested by Zel `dovich that these cosm strings might provide the initial density perturbation that lead to gravitational condensation of galaxie This idea was refined into a very attractive theory galaxy formation by A. Vilenkin and others. The theory can explain rather well the correlation of large clusters of galaxies. It depends, however, on an assumption about the density of strings produced at the time of the primeval 'phase transition'. We cannot now observe this vanished density. But Zurek's idea is to test the broad validity of the assumption on superfluid helium. The test is believed to be relevant to the theory of galaxy formation because of the presumed universality of behaviour near a phase transition. The mathematical model underlying the symmetry breaking involved in phase transition of helium is similar to the Higgs model, the paradigm for discussion of spontaneous symmetry braking in field theories on which Big Bang cosmology is based. Hence if the symmetries of the problem are the same, we can reasonably expect the same qualitative behaviour despite the very different scales of a laboratory experiment and a cosmological conflagration. Vortex lines in the helium experiment should be a good analogue of at least one class of cosmic strings.

## Gravity Waves

Einstein's equations of general relativity *in principle* show that the rapid acceleration of a massive object generates a wave-like disturbance in the space-time continuum wherein it moves. Again *in principle* this perturbation of the gravitationa field would induce mechanical strains in any rigi system which could be detected as vibrations or smal changes in length. The theory is now well understoo and says pretty clearly that no known astronomica process, such as the collapse of a star, would produc anything like sufficient gravitational radiation to be detected by any mechanical system that could be built on earth.

Nevertheless, in the early 1960s, Joseph Webe of the University of Maryland set up a 'gravitationa antenna' — a $1\frac{1}{2}$ ton cylinder of aluminium delicately suspended and isolated from all othe influence save those of a extra-terresterrial source o gravitational waves. The vibrations of this cylinde were then recorded by instruments so sensitive tha they could detect length variations as minute a one-millionth of the diameter of a single atom Naturally the observed output of the apparatus i fluctuating 'noise' due to innumerable small disturb ances that could not be completely screened. Th problem then was how to salvage the signal — th particular wiggle due to the passing of a gravitationa wave through the antenna — from the noise of othe disturbances to which it is exposed. It is not possibl to detect it by mere inspection of the record.

To solve this problem, Weber set up tw

identical antennas one in Maryland and the other in Chicago, 1000 km away. In 1969, he reported a number of 'identical wiggles' in both the antennas. He claimed that their appearance was evidence of gravitational waves from an extra terresterial source. For it was very unlikely that the same extraneous force producing the 'noise' could be acting simultaneously at such distant points, unless indeed it was of extra-terrestrial origin. However, other groups of physicists, in many countries, constructed their own gravitational antennas to look for similar signals. They found no evidence to confirm Weber's claim.

Direct detection of gravitational waves is still one of the most challenging and difficult problems in experimental physics. Its solution will be of great significance both in astronomy, where new information about violent interactions in the universe may be obtained, and for physics, where fundamental aspects of relativity theories may be checked with direct observation. Indirect evidence for the existence of gravitatonal waves has been provided by observations on the binary pulsar PSR 1913+16. It has now encouraged experimental physicists to design new detectors for gravity waves. One way of screening the apparatus from the effects of extraneous disturbances like seismic, atmospheric, and man-made noise is to make the whole system spaceborne. This could be done by recourse to laser interferometery between test masses in satellite spaced a million kilometers or more apart. But it wil take several decades to set up such an apparatus. I the shorter term, an interesting detector of intermediate sensitivity has been proposed by Bragnisky an Thorne. Their proposed 'skyhook' detector woul consist of two masses on each end of a long cable wit a spring at the centre, the whole system bein arranged to orbit in space. By sensing the motion o the test masses as transmitted to the spring a search for gravitational waves could be carried out with a low frequencies as $10^{-1}$ to $10^{-2}$ cycles per secon (Hertz). While space experiments can only be performed in the rather distant future, physicists ar busy exploring the potential of ground-based experiments of inferior but acceptable sensitivity. They wil operate over a frequency range of several tens o Hertz to a few kilo Hertz. These experiments ar aimed at the detection of gravitational waves fro sources such as stellar collapses, coalescing binar stars, and fast pulsars. Astrophysical models ar somewhat uncertain. But a strain sensitivity of $10^{-2}$ — $10^{-22}$ over a kilo Hertz bandwidth should b adequate for th detection of fast-pulsed sources, an $10^{-27}$ over a narrow bandwidth would be an interesting level for pulsars.

At present a number of prototype detectors ar under development. When developed there ar plans to have two in the United States, one each in Germany, Scotland and possibly in France as well. If the construction of these detectors proceeds as planned, there is a very real chance of detecting gravitational radiation from astrophysical objects within a decade. By then certain of the spaceborne experiments would also have been performed. Evaluation of results from the experiments on earth and in space bids fair to open new vistas in astonomy.

## Periodic Cosmic Catastrophes

A well known cosmic catastrophe is the extinction of giant dinosaurs about 65 million years ago. But there have been lesser known but equally indubitable mass extinctions of the then prevailing life 250, 460 and 650 million years ago. They seem to have occurred periodically at intervals of roughly 195 million years. The only natural cycle of comparable magnitude is the "galactic year", the time it takes our solar system to orbit once around the centre of our galaxy, the Milky Way. This "galactic year" is 230 million years long.

It has been suggested that the main cause of such major periodic extinctions as the fossil record now seems to corroborate is an invisible black hole about 7700 light years distant from the galactic centre against 30,000 light years of our own solar system. It too orbits around the galactic centre, but being closer it takes only 107 million years to do so. Assuming its existence and location it is not difficult to show that this putative black hole has a "close encounter" with our solar system once every 195 million years. Now if it happens to be a rotating black hole — a fairly likely contingency — it continually squirts out a beam of electrons and positrons, sweeping out a disc of the galaxy that is hidden from our view at present being in the other side of the Milky Way. But when both our sun and the black hole happen to be on the same side of the galactic centre, as they do every 195 million years, a mere whiff of this lethal blowout from the black hole could easily disrupt the ozone layer in the upper atmosphere that shields life on earth from the deadly ultraviolet rays of the sun.

## The Atomic Hypothesis

If one were to summarise the whole of physics in a single sentence, it would be a statement of the Atomic Hypothesis. The hypothesis states that the endless diversity of matter we observe in the Universe is the outcome of a few types of indivisible particles moved around by an equally few kinds of fundamental forces. It is an old speculation introduced by the Greek philosopher, Democritus, as a cohering principle. It owes its cohering power as much to the economy of particles as that of the forces acting between them and the laws of nature that govern their action. Little would be gained in simplifying the specturm of particles if the number of forces and laws of nature were thereby increased. As it happens, there has been a subtle interplay between the list of indivisible particles and that of fundamental forces throughout the history of physics.

During the last two centuries the Atomic Hypothesis has made a great leap forward. It is no longer a mere philosophic speculation of little value. It has now become a well-founded scientific principle of immense power. Even as early as the turn of the 18th century it could explain a variety of physical phenomena by assuming that all matter consists of indivisible atoms moving under the influence of four fundamental forces, namely, gravitation, electricity, mangnetism and the short-range cohesive force holding together atoms of matter. By the close of the 19th century the list of basic constituents grew implausibly long when the number of supposedly indivisible chemical atoms, and hence the species of atoms, approached 100. The discovery of atomic structure in the 1930s resolved the problem. It was shown that all species of atoms were made of a set of satellite electrons orbiting around the atomic nucleus. Since the atomic nucleus turned out to be a jumble of only two types of elementary particles — protons and neutrons — the number of really elementary or indivisible particles of which all matter is made stood at three — proton, neutron and electron.

At the same time the number of fundamental forces was reduced from four to three. This reduction came in the wake of a series of remarkable experimental and theoretical discoveries which showed that both electricity and magnetism are actually manifestations of a single basic force we now call eletromagnetism. The discovery of the atomic structure as a shell of electrons orbiting round a neclueus of protons and neutrons brought about a further reduction. Although an atom is electrically neutral overall, its constituents are not. Its two basic constituents — electrons and protons — are electrically charged. The former carries a negative and the latter a positive charge. Because of their electrical charge the short-range cohesive force that held the atoms and their aggregates, the molecules, was shown to be a consequence of complicated electromagnetic interactions of positively charged nuclei and negatively charged electron shells.

When the neutral atoms are far apart, there are practically no electromagnetic forces between them. But when they are sufficiently close together, the charged constituents of one atom are able to "see" and influence the inner charges of the other, leading to various short-range attractions and repulsions. These forces give rise to chemical bonds between atoms called valency bonds. As a result of these developments the earlier cohesive force was denoted from the rank of a primary fundamental force to that of a secondary derivative one. Thus the number of fundamental forces was reduced from four to only two — gravitation and electrmagnetism.

However, further exploration of the atomic nucleus — a jumble of protons and neutrons — raised the question of its stability. How can that the mutually repelling positively charged protons in the nucleus do not fly as under? The problem was solved by the introduction of two new short-range fundamental forces — the so-called "strong" and "weak" nuclear forces. This parsimonious view of nature with only three indivisible particles and four fundamental forces did not last long. It was rudely shaken by the great proliferation of elementary particles during the two decades following the end of the second world war. It turned out that protons and neutrons are only two representatives of a very large family of elementary particles now called hadrons, meaning heavy particles. Likewise, the electron in turn was recognised as only a representative of another family of light elementary particles now called leptons. By the mid-1960s the number of fundamental forms of matter — the twin family of hadrons and leptons — again swelled to over 100.

The belief (or prejudice?) that nature is parsimonious and provides only a few truly fundamental building blocks of matter prompted the Nobel Laureate Physicist, Murray Gell-Mann, to propose that all varieties of hadrons are mere combinations of just three types of still more elementary or indivisible particles he called quarks. Unfortunately the subsequent developments in the 1970s and the 1980s have again eroded the economy of his quark model. Whereas it originally postulated only three quarks and three leptons, there are now believed to be eighteen species of quarks and six of leptons besides a dozen other more esoteric particles that act as carriers of fundamental forces. But the known properties of matter are not so numerous or diverse as to require such a profusion of 24 particles to represent them all. Attempts are, therefore, now under way to discover a still simpler or more economical scheme than the currently prevailing quark model.

The first such simpler scheme of quark substructure was mooted in 1974 by Jagdish C. Pati and Abdus Salaam, who have since reverted to the topic in collaboration with John Strathdee. Their model assumes that quarks in their turn are made up of three types of still more elementary particles called preons. Many variations of their preon model have been proposed by other physcists. A still simpler model of quark and lepton structure is the rishon model first proposed by Haim Harari in 1979 and further developed by others in the last three years. Its latest version postulates just two species of building blocks called rishons — rishon being Hebrew adjective meaning primary. Although none of these newer models yet provide an adequate theory of quark and lepton substructure, their underlying strategy is the same as has repeatedly worked before in going from gross matter to the molecule, from the molecule to the atom, from the atom to its nucleus, from the nucleus to the proton to the quark. One is reminded of the French adage: *Plus C a change, plus ce'st la mema chose.*

## How Many Dimensions does our World have?

Ever since the formulation of general relativity by Albert Einstein in 1914 every schoolboy knowns that we live in a four-dimensional world. Four-dimensional, because every event must occur somewhere in 3-dimensional space at some instant of one-dimensional time. By thus embedding events in a four-dimensional manifold of space-time Einstein took the first step towards geometrizing physics that seems to be reaching its climax now seventy years later.

Einstein began his geometrization of physics by replacing the force of gravity by an enigmatic geometrical distortion or curvature of our space-time manifold, the stage of all that happens in the universe. In particular, he showed that the earth moves in an elliptic orbit round the sun not because it is pulled by the sun's gravitational attraction as Newton demonstrated three centuries ago. It simply moves along a "path of least distance" (technically called "geodesic") in a weird sort of wrinkled space-time in the vicinity of our sun.

The great success of Einstein's theory of space-time curvature in explaining gravity inspired physicists to essay a still more comprehensive geometrization of space-time manifold to include both gravity and electromagnetism in the ambit of its sweep. The most successful of these attempts was that of Theodor Kaluza in 1921. He showed that electromagnetism can be regarded as a form of gravity provided an additional fifth dimension is added to the four of space and time. With this addition electromagnetism merely becomes the gravity of the fifth dimension. As the addition of a fifth dimension to the four of space-time appeared to lack credibility, attempts were made to bridge its credibility gap. The Swedish physicist, Oskar Klein, tried to do so in 1926 by claiming that the fifth dimension was not perceptible because it is "shrunken into invisibility". It is like looking at a thin rope from a far. It then appears as an unidimensional line. But on closer scrutiny each point on this line is really a tiny circular disc. Klein proposed analogously that what appears to us to be a single structureless point in space is in reality a tiny circle going around the shrunken fifth dimension. We do not notice the extra dimension as it has been shrunken or rolled up on itself to too small a size to be perceptible. The Kaluza-Klein theory, however, remained a mere mathematical curiosity for several decades. But it has now been revived in the wake of recent successes of what are called unified field theories. They are so called because they seek to unify all the four fundamental forces of nature — gravity, electromagnetism, 'weak' and 'strong' nuclear forces. As we have seen, the Kaluza-Klein theory unified gravity and electromagnetism by grafting a single extra dimension onto the four of our spacetime manifold. Extending their theory to unify the trio of forces — electromagnetism, 'weak' and 'strong' — is a much more demanding task requiring still more dimensions of space. It seems that such an extended unification would require seven more "shrunken" dimensions, a total of eleven in all. Theoretical physicists are now busy carving out the 11-dimensional geometry of a space-time manifold, whose knots, kinks and curvatures become the force and matter of our perception.

Their work seems to suggest that when the universe was created with the primeval "big bang", all the 10 dimension of "space" (bar the eleventh one of time) existed on an equal footing. But seven of them soon spontaneously decayed rolling themselves into seven-dimensional "distorted" "spheres" too tiny to be seen by us.

The reason why we require just seven additional dimensions (neither more nor less) is this. Studies of the geometrical properties of multi-dimensiona spaces by the French mathematician, Elie Cartan, i 1920 have shown that a seven-dimensional analogue of a sphere has the right number of additiona symmetries required to make the hitherto mos successful unified theory, namely, the Weinbger-Salam unification of electromagnetism and 'weak nuclear force, as a special case of the gran unification of three of the four forces that it seems t accomplish.

## Seven States of Matter

Our everyday experience of things tells us tha matter on earth exists in three distinct forms — soli liquid and gaseous like liquid water appearin sometime as solid ice and sometime as gaseou steam. But when we consider all matter in the universe as a whole, we find that it exists in several other states not ordinarily encountered on earth. Although these states of extraterrestrial matter are very varied, they may be broadly classified into four basic kinds. They are plasma, degenerate, Neutron, and black-hole states of matter.

Plasma state is the state of matter when its temperature is so high that it ceases to remain a hot gas. Instead the atoms of the hot gas are split apart into their constituent electrons and nuclei to make a glowing plasma. Plasma, therefore, is a hot gas of electrically charged particles like free protons and electrons. This is the state of matter of which stars like our own sun are made.

"Degenerate" state is the state of matter of which stellar *corpses* called white dwarfs are made of. White dwarf is the terminal state in stellar evolution when a moderate sized star has completely burnt out its resources of nuclear fuel and can no more produce the energy with which it shines. Matter in "degenerate" state is so dense that a match box full of it weighs several tons.

"Neutron" state is the stuff of the debris that a massive star leaves behind when it explodes as a supernova. Neutron stars are even denser than white dwarfs.

Finally, "black-hole" state is that speculative condition of matter when millions of stars are packed within the eye of a needle! It is, therefore, so infinitely dense that its gravity traps even its own rays of light that it emits is virtually invisible.

It is that "singular" state of matter where almost all its diverse attributes disappear not unlike the grin of the vanished Cheshire Cat in *Alice in Wonderland*.

## The Ultimate State of Matter

The three states of matter — solid, liquid and gas — we are all familiar with, is not the whole story. We know that each of three states gives rise to the next by heating like ice turning into water and water into steam. But physicists have now discovered that new states arise when temperatures are raised still further. At several thousand degrees gas will ionize into a plasma with all its atoms broken into their nuclei and satellite electrons. At several million degrees the atomic nuclei in turn are broken into individual protons and neutrons. At still higher temperatures even these nuclear particles fragment into quarks of which neutrons and protons are made.

At each successive phase transition, some structure is lost. Solid ice loses its crystalline structure on melting into water. Boiling water becomes a chaotic melange of molecules, and with higher temperatures the molecules and eventually the atoms themselves fragment into subnuclear particles. Is there an ultimate limit to this continual fragmentation? Do the subnuclear particles like quarks and leptons fragment further to give rise to yet another state of matter?

Some theoretical physicists believe so. According to their speculation the ultimate state of fragmented matter is that weird condition with which our universe originated with a big bang some 15-20 billion years ago. They believe that at the instant of the big bang the ambient temperature of the universe was more than $10^{30}$ degrees K. Under these Draconian conditions matter appeared in its primeval state of fragmentation smashed into its ultimate building blocks with the complete obliteration of the individual identifies of even quarks and leptons.

All the manifold diversity of present-day matter was merged into a single ultimate state at the instant of creation. In exactly the same manner all the four fundamental forces of nature-gravitation, electromagnetism, weak and strong — that control the structure of our existing macro and micro worlds merged into a single unified force with physics reduced to its basic simplicity.

Alas! theoretical physicists have yet to discover this 'simple' law of unified force. All that their theorizing has been able to do sofar is this. First the temperature of the primeval fire ball plummeted from quasi-infinite values at the outset to a mere $10^{10}$ degrees K within one second! For about the brief span of $10^{-35}$ seconds the temperature could have been $10^{30}$ degrees K, high enough for the predicted ultimate phase of matter to have had a fleeting existence. Obviously we will never be able to duplicate temperatures of this order to see what such an ultimate state of completely fragmented matter looks like.

## Stellar Deaths

There are three ways a star can die. If it is of the same size as our sun, it will exhaust its hydrogen fuel, expand to a red giant, and then slowly shrink to a white dwarf. Eventually it will cool to a black dwarf, permanently embalmed corpse that never changes.

If a star is moderately more massive than our sun, it is likely to explode into a supernova leaving a still more dense residue of a neutron star, astronomers call pulsar. Pulsar, because it sends out absolutely regular pulses or beeps of radio waves, sometimes beeps of visible light.

Finally if a star is much more massive than the sun, it is expected to expire in a manner so bizarre that its ultimate fate is still an unresolved mystery. On expiry it undergoes a catastrophic implosion, a sort of explosion in reverse, so that even neutrons are unable to withstand its enormous gravitational compression. All particles are crushed out of existence and the laws of physics cease to have any meaning. It has entered a "singular" state called black hole.

While our Milky Way is littered with Stellar corpses of the first two kinds — white/black dwarfs and pulsars — no corpse of the third type — a black hole — has yet been discovered. It is true that there are some spots in the sky where astronomers think they see something that fills the bill for a black hole — notably the strong X-ray radiation coming from the vicinity of a giant star in the constellation of Cygnus. But what they see may have some more conventional explanation. No one yet knows what.

## Gravitational Collapse

Consider a very large sphere of uncharged matter such as a spherical dust cloud. The cloud will begin to shrink under its own gravitation. But the shrinkage will cease as soon as the elastic forces developed by the compression of the cloud begin to balance the inward pull of gravity. These compression-resisting cohesive forces at any point P within the sphere arise from the interactions of only particles in the immediate vicinity of P with little or no contribution from particles further away. Their magnitude at P is, therefore, not appreciably affected by the size of the sphere. But the compressional force of gravity at P arises from contributions from all particles of the sphere whether near or far. Consequently if the radius of the sphere is sufficiently large, elastic forces at P due to only nearby particles will not grow as fast as gravitational compression. As a result they will not be able to withstand gravity and the sphere will continue to shrink into evanescence. This is the simplified argument for gravitational collapse.

A greatly refined version of the above argument was given by the German astronomer, Karl Schwarzschild, soon after Einstein published his general theory of relativity. He showed that continual compression of a body under its own gravitation would, under certain circumstances, make it so superdense that even light cannot escape its gravitational pull. The ultimate radius at which an object becomes so superdense that it is strong enough to prevent light, matter, or any kind of signal from escaping is called "Schwarzschild radius". For a mass equal to our sun's, the radius is a few kilometers. When a supermassive star compress to the size of its Schwarzchild radius, it is believed to become an invisible black hole.

A curious feature of the Schwarzchild's calculation is the existence of a space-time "sigularity" at the core of every black hole. It is a term mathematicians use to indicate a point at which something "sigular" *alias* catastrophic happens to the solution of an equation. In this case the calculations show that space-time curvature becomes infinite, which is to say that it collapses into a single point. At that point, gravitational force and density both become infinite.

## Black Holes

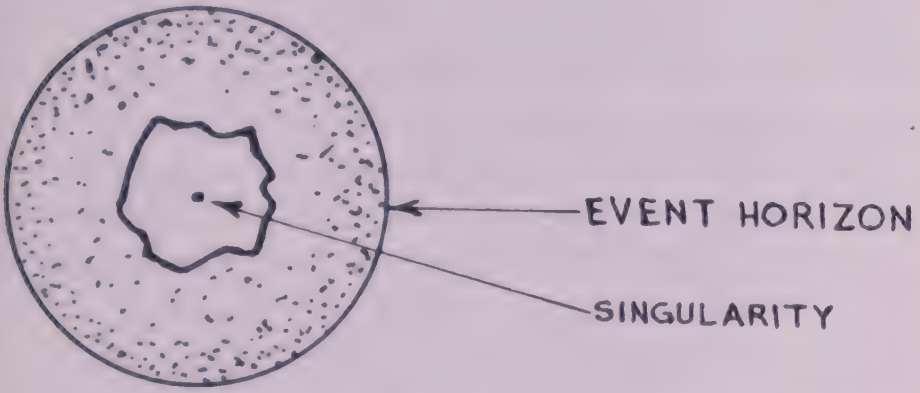
*Black Holes* are the invisible debris left over by the gravitational collapse of a massive body such as a star. Einstein's general theory of relativity predicts that gravitating mass could collapse under its own gravitation into a "singularity" of infinite density. Such a superdense "singularity" or black hole traps inside itself all radiation so that it cannot be seen even "in principle" by an out side but nearby observer. In other words, it is totally black not merely in name but in substance too.

However, Stephen Hawking has recently pointed out that this argument is based on Einstein's general relativity. But general relativity, though one of the two greatest achievements of the 20th century, is incomplete because it does not incorporate the other, namely, the uncertainly principle of Quantum

Mechanics. It states that certain pairs of quantities, such as position and velocity of a particle, cannot be predicted simultaneously with complete accuracy. The more accurately one predicts the position the more erroneously will one be able to predict its velocity, and vice versa. By applying this uncertainty principle to the gravitational collapse of localised regions such as stars he has shown that black holes are not completely 'black'. They can and do radiate particles and radiation like a hot body with a temperature which becomes higher and higher as the mass of the black hole becomes smaller. Since the radiation carries away energy thereby depleting its mass, a chain reaction ensues wherein the more it depletes its mass the more it radiates. There can be only one outcome of such a process — its complete disappearance in a tremendous outburst of radiation.

## Naked Singularity

If space-time singularity actually occurs and can be observed, it is called a "naked singularity". No one has as yet seen any. It is possible, as suggested by the brilliant theoretical physicist, Roger Penrose, that space-time singularities *can* occur, but are prevented from becoming naked by a "cosmic" censor. This censor conceals them, so to speak, inside an "event horizon" that prevents them from interacting in any way with the outside universe. See Figure.



A schematic diagram of a Black Hole showing the event horizon and the singularity.

But a major discovery by the legendary mathematical physicist, Stephen Hawking, seems to suggest that naked singularities may be able to get round the cosmic censor of Penrose. Hawking has used quantum theory to show that in the powerful gravitational field surrounding a singularity or black hole there is constant creation of particles of every kind and their antiparticles. Some of these particles fall into the hole, others escape as radiation. There is thus a constant leakage of energy and a flux around the hole that could be observed.

Hawking also believes that the big-bang creation of our universe may have been chaotic enough to have created billions upon billions of mini black holes, each smaller than the nucleus of a hydrogen atom but containing a mass of a few hundred million tons. If these primeval miniholes do exist, our universe would be much more massive than the current estimates based on observable matter indicate. In that case our expanding universe will sooner or later begin to collapse back into the primeval black hole from which it emerged with a bang some 10-20 billion years ago. It is not unlike a ball thrown vertically upward returning back to its starting point after a while.

## Cosmic Magnetic Fields

That our earh is a huge magnet with its pole located near its geographical north and south poles has been known ever since the advent of the mariner's compass a few centuries ago. Now spacecrafts carrying magnetometres near planets have revealed that all planets with the exception of Venus and Mars have magnetic fields of their own. The fields range in strength from $3.5 \times 10^{-3}$ gauss at the poles (Mercury) to eight gauss at the poles (Jupiter). Our own earth's field, in comparison, is about .6 gauss at the poles. We are not yet certain about Uranus and Neptune. The Voyager II spacecraft which carries a magnetometre will pass close to Uranus in 1986 and later to Neptune. It is expected to show magnetic fields on both because of their similarity to Jupiter and Saturn.

The Sun too has a magnetic field though it is, unlike that on earth, an oscillating one. It is directly observable as the top of the convective zone that generates it can be seen. Twinned sunspots and bipolar magnetic regions in general are, in fact, local bulges in its internal magnetic field pushed to the surface by magnetic buoyancy. The fields just below such bulges are reckoned to be at least as strong as 200 gauss and may well exceed 10,000 gauss. But the surface field is much weaker with a strength of perhaps five to ten gauss.

Although other stars in our galaxy are too far to make possible the detection of such fields, their existence can be inferred from the presence of activity very similar to that sponsored by solar magnetic field on the Sun. On such evidence it appears that most stars have magnetic fields at least as strong as that of the Sun. There is, however, a class of stars whose magnetic fields are so powerful that we can measure their strength from earth by the extent to which the two states of polarization of a given spectroscopic line are shifted from the position of the unpolarized line. Such, for instance, is the case with Magnetic A stars with fields of up to 34,000 gauss. Some white dwarf stars have fields from $10^7$ to $10^8$ gauss and their next of kins, pulsars of even $10^{12}$ gauss. Recent evidence shows that our galaxy too has a dominant field of strength ranging from $2 \times 10^{-6}$ to $3 \times 10^{-8}$ gauss and so do other galaxies. We are not yet certain about the existence of magnetic fields in intergalactic space, that is, space between galaxies.

It is the existence of magnetic fields that makes our Universe a violent one. They are the cosmic agitators which give rise to the continued violent events of the cosmos from auroral displays in the earth's atmosphere to stellar flares nova eruptions and X-ray emissions as also the massing of interstellar gas clouds in galaxies.

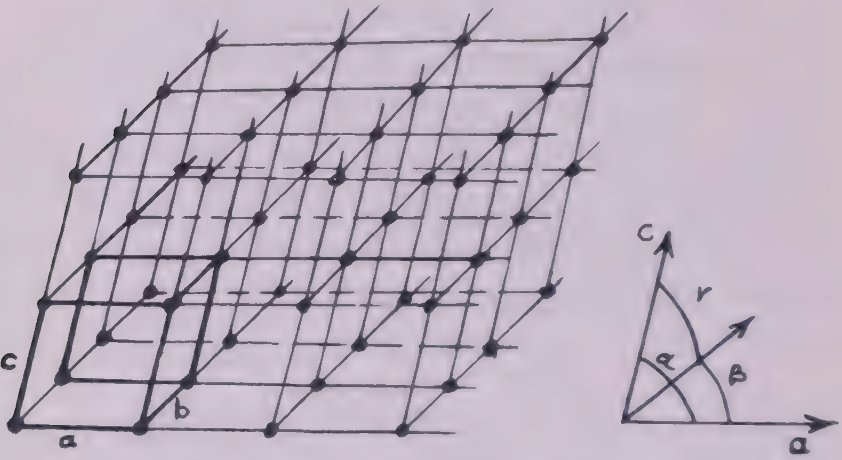
The explanation for the generation of cosmic magnetic fields is what may be called the dynamo mechanism. A dynamo converts the energy of motion of a metallic conductor into the energy of an electric current and a magnetic field. But such a conductor need not be a metallic solid like the rotor of a power generator whose mechanical motion is converted into electricity. It can be any electrically conducting fluid capable of supporting the current associated with the field. The ubiquity of such fluids in the Universe is obvious from the fact that most planets have a molten core; stars are composed of ionized gases, and nearby all space is filled with a gas that has enough free electrons. All these cosmic fluids are good conductors of electricity. Further most of such cosmic fluids are in non-uniform rotation as well as in turbulent or cyclonic motion.

This is a patten of motion which is tailor made to amplify such weak primeval magnetic fields as may be initially present.

Unfortunately, we do not yet know how these initial primeval fields that the dynamo mechanism amplifies actually arose in the first place. One plausible surmise made in 1941 by Ludwig F. Biermann is that they were created by the so-called "atomic battery" effects in the moving ionized gas of the stars. He tried to show that if a star was initially free of magnetic field, his battery effect would over an extended period build up a weak seedling magnatic field which would be later amplified by the dynamo mechanism already described. For battery effect alone cannot account for fields of the magnitude we observe today. His explanation is not yet universally accepted. Nevertheless, in the absence of anything better, it does guarantee that stars and galaxies are seeded with weak magnetic fields on which the dynamo mechanism on the cosmic scale can then operate.

## Solid State Pollution

Solid state physics is largely a study of crystalline solids. They are bodies whose individual atoms or molecules are located regularly in three-dimensional space forming a periodic array of points repeating itself endlessly in a regular rhythm as shown in figure below:



A lattice of points, showing the unit cell in heavy outline and three fundamental translational vectors a, b and c.

The cubic unit cell whose corners are the atoms (molecules) repeats itself in space to generate the crystal. Early concepts of solid state physics were developed on the model of such a perfect crystal—a lattice of identical cubes endlessly repeated.

It was, of course, recognised from the outside that real crystalline solids were not as perfect as the ideal scheme described above. But for a long time it was considered sufficient to regard them as small distortions of the perfect host lattice. These small distortions were treated as isolated defects that did not matter. It is now being increasingly realised that the 'defects' of crystals are often the crystal's real virtues. Consider for instance, a crystal of germanium, a brittle white metal. In its perfect state it acts as an insulator. But when 'doped' or 'polluted' with a small amount of impurity such as arsenic the 'doped' crystal becomes a semiconductor, the stuff of which the ubiquitous transistor is made. The emergence of newly developing technologies like 'doped' and amorphous semiconductors, the progressive technologies like 'doped' and amorphous semiconductors, the progressive refinement of semiconductor devices and unerionic conductors now demands a fundamental understanding of processes involving defects, that is, of doping crystal in appropriate ways. The interaction of defects as in the evolution of silicon chips by the simultaneous diffusion of two impurities in silicon is evidence of the enormous benefits accruing from what a key-word conscious researcher has called the "ecology of solid state pollution".

## Fluid Mechanics and Arms Race Models

The common factor that links these two disparate disciplines is this. In both we encounter two types of phenomena — one predictably determinate and other chaotically unpredictable. Consider first Fluid Mechanics. It deals with the former type phenomena like the motion of a system of *discrete* particles or projectiles on the basis of Newton's equations of motion. Given the forces and the initial positions and velocities of the system of *discrete* particles, one can readily determine specific well-defined orbits in which they will move. The equations enable us to predict, at least in principle, the subsequent positions of the particles at any given instant of time. The case is very different when similar concepts are applied to the motion of *continuous* fluids like liquids and gases. For actual fluid motions such as the flow of water in pipe are of two fundamentally different kinds. One is the regular or *laminar* flow where all particles of water move uniformly in the same way along parallel stream lines like the orderly route march of a regiment. But such an orderly march turns suddenly into the hurly-burly of a turbulent mob when a certain parameter of the flow called its Reynolds number exceeds the critical value 2000 (Reynolds number is the ratio $ud/v$ where $u$ is the velocity of water flow, $d$ the diameter of the pipe and $v$ its viscosity). This changed flow of water is known as turbulent (or chaotic) flow.

The laminar flow like the motion of discrete particles is predictably determinate. The turbulent flow, on the other hand, is chaotically unpredictable. As a result the more complex nonlinear equations of fluid dynamics may represent either laminar or turbulent character. They also represent the nature of flow transitions from laminar to turbulent as some parameter or combination of parameter crosses some critical values or the thresholds.

Laminar flow implies predictable behaviour. Stream lines which start off near to each other keep together. Knowledge of the motion at one point in the flow at one instant implies the kowledge of the motion at neighbouring points in space and time. Turbulance, in contrast, is chaotic. Knowledge of the motion at one location and at one time tells us nothing about the motion at nearby points at same time or at the same point at later times. Prediction is, therefore, inherently impossible. Hence the same set of equations (or, mathematical model) allows *regular* and therefore predictable behaviour under some conditions and *chaotic* and therefore unpredictable under others. This breakdown of predictablility in certain systems is precisely the feature that a model simuling chaos in the wake of war should possess. No wonder it has led a number of researchers to design analogously very simple nonlinear models of the arms race, the precursor of war.

The underlying rational of such models is as follows: Civilized life is largely predictable. We know, for example, what people in a city will do on a normal day when they wake up. Similarly, the formulation and carrying out of policy requires a reasonable ability to predict the future given some knowledge of the present. The same requirement for predictability holds for the relationships between nations, whether they are engaged in normal international competition on in a hostile arms race. But the history of nations is replete with instances of loss of control, by one or more governments, as they jump from peace to war. Consequently any plausible model of an arms race between nations should include conditions of predictable (laminar) behaviour, conditions of chaos (or turbulence) and transitions between one regime to another exactly as models of fluid motions do.

Several such models of the prevailing arms race between the super powers have been devised in the past few years. They are as yet not a credible representation of world affairs. But they are a necessary prelude to any realistic model of a two-party arms race. It will most probably include nonlinear terms of the type encountered in fluid dynamics to provide for a transition from a predictive state of affairs to chaos. The creation and analysis of such Chaos — prediting models and the practical applications of the insights they provide can perhaps contribute to avoidance of such chaos in real life. Who knows?

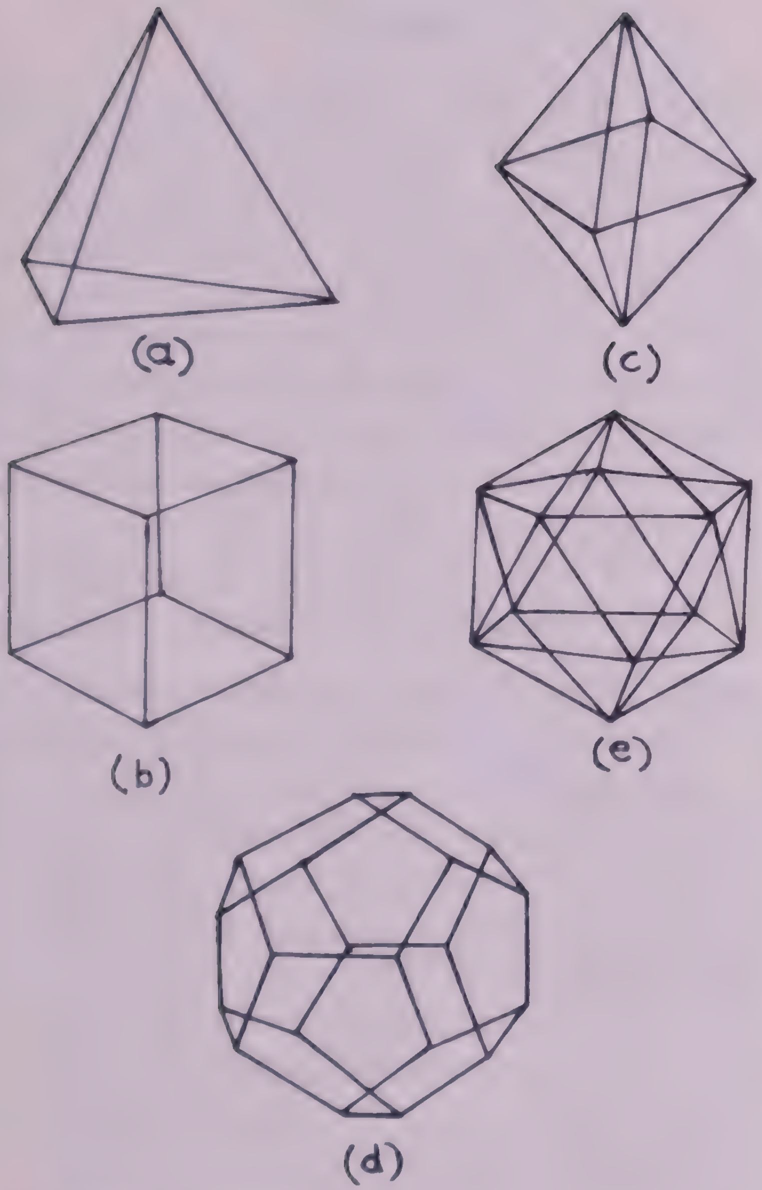
## Platonic Chemistry

Plato was greatly captivated with the Phythagorean discovery that although the number of regular polygons — closed two-dimensional figures with all sides equal — is infinite, the number of their possible three-dimensional analogues is restricted to only five. For it was shown by the Greeks that there can be no more than five *regular* polyhedra, that is, solids with identical or congruent faces. These five platonic solids are the regular tetrahedron (4 faces), cube (6 faces), Octahedron (8 faces), dodecahedron (12 faces) and icosahedron (20 faces).

In his *Timaeus*, Plato, therefore, took four of these regular solids — tetrahedron, cube, octahedron and icosahedron — and assumed them to be the shapes of the corpuscles of his four basic elements — fire, earth, air and water — which in their turn are, in his view, the immediate constituents of all organic and inorganic matter.

Chemists nowadays do not take Plato's speculations seriously. Their basic elements are a very different kettle of fish. But they have recently begun to build molecules in the shape of these regular polyhedra of Plato. They believe that the high degree of symmetry of the Platonic molecules will make it possible to study the properties of chemicals bonds in greater depth than has been possible hitherto. Accordingly a team of molecular chemists under Leo A. Paquette of Ohio University has recently synthesized a molecular dodecahedron. Paquette began with the molecule of hydrocarbon cytopentadiene made up of five atoms arranged in a regular pentagon that eventually becomes one of the faces of the dodecahedron. Other faces of the dodecahedral cage are then added in successive steps in such a way that the intermediate molecules remain roughly symmetrical.

The final molecule called dodecahedrane is last of the five regular Platonic solids to be synthsized. Cubane, in which carbon atoms from the vertices of a cube and a hydrogen atom is attached to each carbon atom, was made in 1964 by Philip E. Eaton and Thomas W. Cole, Jr., of the University of Chicago. The corresponding four-faced carbon skelton, the so-called tetrahedrane, has not yet been synthesized though a close analogue has been. Both the other two remaining Platonic molecules octahedrane, the eightfaced organic molecule, and icosahedrane, the twentyfaced one—are probably too unstable to exist though molecules in these two forms can be readily synthesized from atoms other than carbon.



Five Platonic Polyhedra:
(a) Tetrahedron (4 faces), (b) Cube (6 faces), (c) Octahedron (8 faces), (d) Dodecahedron (12 faces), (e) Icosahedron (20 faces).

# Decibel

*Decibel* is a unit for comparing the levels of electric or accoustic power, that is, loudness of sounds. It is more convenient to express them as ratios rather than in their absolute magnitudes. Consider, for instance, the loudness of two sounds like the roar of a Ramjet engine and a barely audible human whisper. The absolute magnitude of total power that they produce in the air around them may be measured in watts. The power of the former is 100,000 watts, while that of the latter is only 0.000,000,001 watt, Ramjet roar is, therefore, 100 trillion times louder than the human whisper.

When measurement extends over such a wide range, it is more convenient to use a geometric, or ratio scale rather the ordinary arithmetic scale provided by the series of whole numbers 0, 1, 2, 3... we use for counting. In the geometric ratio scale numbers increase like, 1, 10, 100, 1000, 10,000... So if we denote them as powers of ten, namely, $10^0$, $10^1$, $10^2$, $10^3$, $10^4$... respectively, we can use their power indices, 0,1,2,3,4... to indicate their magnitude in a new unit called bel. Since a decibel is one tenth of a bel, the same numbers, 1,10,100,1000,10,000... may also be denoted as 0,10,20,30,40... decibles respectively.

Accordingly if we reckon the loudness of the human whisper at the threshold of hearing as zero decible, then that of the Ramjet roar ($10^{14}$ times louder) will be 140 decibles. Likewise, the strength of the human voice at the conversational level ($10^4$ times stronger) will be 40 decibles, every increase of ten decibles meaning a ten-fold rise in its loudness.

In brief, decibel unit is to sound what degree of temperature is to heat. Decibles denote the loudness of a sound, degrees of temperature the warmth of a thing, or environment.

## Fractal Geometry

In a recent book titled The Fractal Geometry of Nature, B. B. Mandelbrot defines a fractal as "a mathematical set or object whose form is extremely irregular and/or fragmented at all scales." Such fractal or irregular objects are antonyms of their more regular and smoother analogues with which ordinary Euclidean geometry is concerned. Since most natural objects ranging from coastlines through land frontiers to trees are extremely irregular, ordinary Euclidean geometry cannot take such fractal objects and patterns in its stride. Mendelbrot shows how to resolve these difficulties by resort to concepts of what he calls fractal geometry.

Consider, for instance, the measurement of land frontiers or coastlines. If we measure their length by means of a given scale, their length should be the same no matter whether the scale is one, ten or 100-kilometres long. And yet L.F. Richardson found long ago that the length of land frontiers and coastlines appears to increase as the scale of measurement is reduced. Thus if the length of the coastline of India is determined using a 100-km measuring scale the answer will be smaller than that obtained by using a finer 10 km rod. The reason is that the finer scale rod will resolve and therefore have to negotiate the longer distance round smaller scale structures such as river estuaries and inlets. It can be shown that if the length of the measuring rod is L, the apparent length of the coastline is proportional to L1-D, where D is a measure of the density with which the curve fills the space (surface or volume) in which it is embedded. D can be interpreted as an anamolous or "fractal" dimension.

There are also some other areas where Mendelbrots' ideas have found useful applications. The most striking ones, are the numerical simulations of a random fractal objects like islands and landscapes, which, though extremely artificial constructs, assume an uncannily familiar appearance when supplemented by appropriate shadowing effects.

# The World of Numbers

Numbers arose when man first began to count. He could do so because he has an inborn *number sense.* It is a faculty that enables even a primitive man living in a wild state of nature to recognise that something has changed in a small collection when, without his direct knowledge, an object has been removed or added to it. No other species, except some birds and insects like the "solitary wasp", possesses it. Although the possession of a rudimentary number sense is a necessary nucleus for the growth of number concept, it is not sufficient. Left to it man would have advanced no further in the art of reckening than crows and wasps have. He advanced because of his other inborn faculty of speech and language, he learnt, through a series of remarkable circumstances stretched over millennia, to greatly amplify his exceedingly slender perception of number by an artifice destined to exert a tremendous influence on his future life. This artifice is counting, and it is to counting that we owe the extraordinary progress which we have made in expressing our universe in terms of numbers.

Counting gave us integers, the stuff of number theory. In the beginning man was so fascinated with his discovery of integers that he began to worship them as is shown by the Pythagorean invocation:

"Bless us, divine number, thou who generatest gods and men....". The explanation for this strange number worship is the fact that "the life of man", to borrow a famous maxim of Montesquieu, "is but a succession of vain hopes and groundless fears." These hopes and fears which to this day find their expression in a vague and intangible religious mysticism took in the early ages more concrete and tangible forms. Stars and stones, beasts and herbs, words and numbers were symptoms and agents of human destiny. This is why the genesis of all science can be traced to magic, mysticism and sorcery. Astrology preceded astronomy, chemistry grew out of alchemy, medicine out of witchcraft and theory of numbers out of numerology. It explains why J. M. Keynes called Newton the first of the new breed of savants we now call scientists and the last of the old called magicians.

Theory of numbers began as numerology, the study of the supposedly occult properties of numbers. These properties of number were based on the Pythagorean belief that all things can be expressed in numerical forms because they are ultimately reducible to numbers. It led to the most absurd yet widely spread forms which numerology took. It was called *Gematria*, a system wherein each letter of the alphabet has the double meaning of a sound and of a number. In this way words or names became numbers. Thus if the name Thamagoras and the word *loisos* (meaning a sort of pestilence) had the same number, the man was 'proved' to be a pest. It was *Gematria* that spurred investigations into individual properties of numbers. Thus six and twenty-eight were deemed 'perfect' because they were the sum of their divisors or factors. Three divisors of 6, namely, 1, 2 and 3 add up to 6 even as 28 is the sum of its five, namely, 1, 2, 4, 7 and 14. Early commentators of the Bible therefore regarded 6 and 28 as the basic numbers of the Supreme Architect. He created the universe in six days and made the moon go round the earth in 28 days. Others even went so far as to explain the imperfection of the second creation because Noah's arc rescued 8 souls and not 6.

The ancient numerologists considered not merely the 'perfection' of certain numbers like 6 and 28 but also their 'amicability'. Two numbers such as 220 and 284 are "amicable" because the sum of the divisors of one equals the other. Thus the divisors of 220 are 1, 2, 4, 5, 10, 11, 20, 22, 44, 55 and 110 and they add up to 284; while those of 284, namely 1, 2, 4, 71 and 142 add up to 220. The two numbers 220 and 284 are therefore "amicable". The amicable numbers were known to the Hindus even before the days of Pythagoras. Their discovery was a problem of great interest and of considerable difficulty. They considered the general question whether there exists an infinity of such couples. But as they could not prove it, they had to remain content with the discovery of about a hundred now known.

## Catastrophe Theory

*Catastrophe Theory* made its debut in 1974 with the publication of Rene Thom's celebrated book *Structural Stability and Morphogenesis*. Thom's book dealt with an area of deep and difficult mathematics involving profound theorems of great interest to the world's finest mathematicians. His ideas were immediately taken up and began to be applied to a great variety of problems, not only in mathematics and physics but also in biology and the social sciences.

Thom's book is an extension and development of a theory of mathematical 'singularity' formulated by H. Whitney in 1955. Whitney pointed that classical calculus considers only smooth continuous processes like the flight of projectiles or smooth progression of waves. But it evades the discontinuities, the breaks and jumps, that can occur in a dynamical process. Mathematicians call such breaks "singularities". The 'big bang' with which our universe originated is one such singularity on the cosmic scale. But smaller scale singularities are extremely common and familiar. Cases in point are smooth flows suddenly turning turbulent in hydrodynamics, regions of intense illumination due to light (rainbow, curves of bright light at the bottom of swimming pools) in optics, propagation of defects in crystals in crystallography, and so on. Whitney's basic study turned the freak mathematical 'singularity' into a focal point for the blending of some of the most abstract areas of mathematics like differential and algebraic geometry, topology, group theory, commutative algebra with some of the most applied like stability theory, bifurcation theory, goemetrical optics, etc. Thom combined the abstract and applied to formulate a comprehensive theory of singularities that could occur in our space time. He suggested that these singularities are the origin of all natural forms that arise in a sufficiently structured system.

Taking his cue from Thom, Christopher Zeeman broadened the singularity theory to handle a great variety of problems in the human and social sciences as well. It was he who suggested the name 'Catastrophe theory' that has since stuck. It claims to illumine an extraordinary world of mathematical modelling — 'an open sesame' to some of our most intractable problems. Has it redeamed its great promise?

In a recent book titled Catastrophe Theory, the distinguished Russian mathematician V.I. Arnold summed up the professional verdict on it: "The nice results of singularity theory are happily not dependent upon the dark mystics of Catastrophe theory." This is merely to say that in most of its serious applications the singularity is treated as Whitney did two decades ago before its formulation by Thom. Clearly catastrophe theory works in physics where singularity theory worked before. But Thom's programme to extend it to take in its stride the general problem of morphogenesis, cognition and the new physics in the style of a generative science of form does not seem to have succeeded yet.

## Taming Infinity

Ever since Zeno astonished ancient Athens by his famous paradox that either a moving arrow does not move or the swift-footed Achilles can never overtake a crawling tortoise ahead of him, infinity has been a turbulent concept subversive of logical and paradox-free reasoning in mathematics. Ancient Greek mathematicians with rare exceptions avoided its use thereby greatly inhibiting the progress of their science. Even two millennia later this *enfant terrible* of mathematics remained so untamed that the Great Galileo himself suggested banning its use in mathematical discourse. It was only around the turn of the century that its subversive turbulence was subdued by George Cantor who devised a neat way of measuring, so to speak, what is almost by definition beyond measurement.

Cantor's way of measuring or mapping infinity is merely matching one infinite collective or set of objects against another very like matching the students in a class with their names in the roll call register. By recourse to an ingenious extension of such a matching operation he showed that just as there is an unending heirarchy of whole numbers 1,2,3....., there is a similar heirarchy of transfinite numbers. In other words, all infinities are not alike. Some are bigger than others. The smallest infinity is that of the unending set of whole numbers 1,2,3.... The next bigger infinity is the set of points on a line segment. If we denote the former infinity by the symbol No and the later by C, the question arises whether or not there is an intermediate infinity bigger than No but smaller than C. Cantor surmised there is *no* infinity intermediate between No and C. This assumption is the famous *Continuum Hypothesis* of Cantor.

Cantor believed his continuum hypothesis to be almost self-evident. But as many of his contemporaries did not share his belief, proving or disproving it became one of the major unsolved problems of mathematics that David Hilbert listed in 1900. The problem was finally solved in 1963 when Paul J.

Cohen showed that we could accept it as true or false without producing any logical contradiction. Cantor's hypothesis is therefore completely neutral to Cantor's theory of infinite sets.

## What is Topology?

Topology is an extension of ordinary geometry which measures lengths, areas and angles and is, therefore, called *metric*. But geometrical objects like points, lines, angles, surfaces and solids, also have some non-metric or non-measurable fundamental properties, that are unaffected when we stretch, twist or otherwise distort or deform them to some other size or shape. Topology is the geometry of such distortions. It studies points lines, figures, surfaces and solids, in fact, anything from pretzels and knots to networks and maps.

In both geometry and topology, the key operation is what mathematicians call transformation. They use it to describe changes of position, size or shape and the word *invariant* to describe properties unaffected by these changes. In ordinary geometry, metric properties are said to be invariant under the transformation of motion. Motion is assumed to have no distorting effect; your book retains its shape even if it is carried from home to office. In topology, the problem is to find the geometric properties invariant under distorting transformation. For example, which properties of a triangle are retained if it is stretched into a circle? Or, what properties of a cube made of modelling clay remain invariant if it is deformed into a ball by kneading?

The great power of topology stems from the fact that its arguments are qualitative and non-numerical. A simple case in point is the problem of a ball thrown vertically upward and returning back to its starting point. One can immediately deduce that at some point on the way it must have been stationary. This conclusion depends, of course, on certain preconceptions about gravity and the continuity properties of space and time. When suitably formulated they form the foundation of topology and analysis. Now in such a simple example an elementary application of Newtonian calculus will give full information about the whole motion, while the topological argument merely asserts the obvious. If, however, a single ball is now replaced by a large number of balls moving in more complicated ways, then direct analytical computation may become too long or too difficult to perform. In such a situation one may settle for some qualitative aspects of various motions, which may be far from self-evident because of the complexity of the situations. In fact, if we replace the balls by planets and proceed to study their motion under their mutual gravitational attraction, extremely difficult and unsolved mathematical problems arise. It was precisely the analytical difficulties of such a many-body problem that motivated the celebrated French mathematician, Heri Ponciare to pursue his pioneering work on topology around the turn of the century.

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